THE DEVELOPMENT OF A MULTI-PURPOSE BEAM/COLUMN TESTING APPARATUS

BY

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DECLARATION

I the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

Date:

C.B. Koen

SUMMARY

A multi-purpose beam/column apparatus is developed to ensure successful testing of structural elements and to optimise the main test floor of the Structures Laboratory of the University of Stellenbosch. An overview of the testing of structural elements is given as background to beam and column testing, with specific reference to the test sample, the test arrangement and the test data. The test arrangement, with reference to the test setup boundary conditions (static and kinematic), and the loading are discussed. A summary of the collection and the processing of the test data is given and frequently used and standard test setup is described.

The requirements and the various components of the testing apparatus are discussed and a three-dimensional CAD model of the apparatus is developed to illustrate the versatility of the apparatus.

A rational planning process is developed to optimise the testing and pre-test planning process with specific reference to the use of the apparatus. This rational planning process is defined as the process of preparing, testing and evaluating structural tests and together with the literature review will ensure meaningful test results.

The use of the apparatus, built by the Department of Civil Engineering, University of Stellenbosch and the use of the rational planning process are illustrated by testing the deflection of a welded truss, from which conclusions are drawn.

OPSOMMING

'n Veelsydige balk/kolom apparaat is ontwikkel om die gebruik van die hoof-toetsvloer van die Struktuur Laboratorium van die Universiteit van Stellenbosch te optimiseer en suksesvolle struktuurtoetse te verseker. As agtergrond tot die ontwikkeling van die MTA word 'n oorsig gegee oor balk-en-kolom toetse, met spesifieke verwysings tot die toets-stuk, die toets-opstelling en die toets-data. Die toets-opstelling word bespreek met spesifieke verwysing na die grenstoestande (staties en kinematies) en die aangewende belasting. Die versameling en die verwerking van toetsdata en die algemeen gebruikte en standaard toets-opstellings word bespreek.

Die vereistes van die verskillende komponente van die apparaat word bespreek en 'n drie-dimensionele CAD model van die apparaat word gebruik om die veelsydigheid van die apparaat te beklemtoon. `n Rasionele beplanningsproses, wat spesifiek verwys na die gebruik van die apparaat, word ontwikkel. Hierdie beplanningsproses wat die beplanning, uitvoer en evaluasie van strukturele toetse insluit, saam met die literatuur agtergrond, verseker sinvolle toetsresultate.

'n Gesweisde vakwerk word getoets om die gebruik van die apparaat, gebou deur die Departement van Siviele Ingenieurswese, Universiteit van Stellenbosch en die gebruik van die rasionele beplanningsproses te illustreer. Gevolgtrekkings word gemaak na aanleiding van hierdie toetse.

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LIST OF SYMBOLS

A	= area of cross section
A_V	= shear area
A_{ne}	= effective net area
a	= end distance of fastener hole
B	= bearing force in member or component under service load
B_r	= factored bearing resistance
B_u	= bearing force in member or component under ultimate load
b	= width of section
b_f	= flange width
C	= compressive force in member or component under service load; axial load
C_r	= factored compressive resistance
C_u	= compressive force in member or component under ultimate load; ultimate axial load
C_w	= warping torsional constant
d	= diameter; deflection
E	= elastic modulus
e	= eccentricity; size (leg length) of fillet weld
f_{cu}	= specific compressive cube strength of concrete at 28 days
f_u	= specified minimum tensile strength
f_{uw}	= specified minimum ultimate strength of welding electrode
f_{vu}	= ultimate shear strength
f_y	= specified minimum yield stress
G	= shear modulus
h	= height; depth of section
h_w	= clear depth of web between flanges, or between web fillets
I	= moment of inertia
J	= St. Venants torsion factor

K	= effective length factor
KL	= effective length
k	= distance from outer face of flange to web toe of fillet of I-shaped section or channel
L	= length of member
l	= length
M	= moment; bending moment
M_{cr}	= critical elastic moment of unbraced beam
M_p	= plastic moment
M_r	= factored moment resistance
M_u	= bending moment under ultimate load
m	= mass
N	= length of bearing of applied load
n	= number
P	= concentrated externally applied load
Q	= prying force in bolt
R	= resistance of member
T	= tensile force in member or component under service load; torsion
T_r	= factored tensile resistance
T_u	= tensile force in member or component under ultimate load
t	= thickness
t_f	= flange thickness
t_w	= web thickness
V	= shear force in member or component under service load
V_r	= factored shear resistance
V_u	= shear force in member or component under ultimate load
W	= total distributed load
w	= unit distributed load
x	= subscript relating to strong axis of section
y	= subscript relating to weak axis of section

Z_e = elastic section modulus

Z_{pl} = plastic section modulus

Δ = deflection

Φ = resistance factor; rotation

1 INTRODUCTION

1.1 Background and Description of the Thesis

Experimental mechanics form an important part of structural engineering, as design formulas are verified and even derived from test results. Experiments also assist students in understanding structural behaviour and design and therefore form an important part of undergraduate study.

Poor test results have no educational nor research value and can be considered a waste of time. The thesis describes the development and design of a beam testing apparatus in order to ensure meaningful test results.

Various literature references to testing structural elements are discussed in order to provide a background to testing beams. This will provide the user with a deeper insight into experimental mechanics, as loading arrangements and loading requirements, static and kinematic boundary conditions and the measurement of test data are discussed.

With reference to the literature study the requirements for a testing apparatus are described. These requirements include flexibility, size, static and kinematic boundary conditions and loading requirements.

The developed testing apparatus, and its various components, are described with reference to the literature study and the requirements. The Flexibility of the Multi-purpose Beam/Column Testing Apparatus (MTA) is demonstrated by means of illustrations.

A rational planning procedure for using the testing apparatus is developed and described to ensure successful testing. This procedure will assist in various stages of the pre-testing decision making process.
In the evaluation of the testing apparatus, it was used as test setup for a diverse range of graduate and postgraduate studies. These tests included testing a truss, a crane wheel on a

crane track, an overhead crane beam and a portal frame. From the performance of the MTA in these tests in reference to the requirements, conclusions were drawn.

1.2 The Objectives of the Thesis

The main test floor of the Structure Laboratory has a loading capacity of 400kN for vertical and 200kN for horizontal loads per fixing point (for a maximum of four points). Fixing points are spaced at 920 mm cross-centres in both directions, the total size of the test floor being 25 x 12 fixing points, or 225 m^2, as can be seen in Figure 1.1.

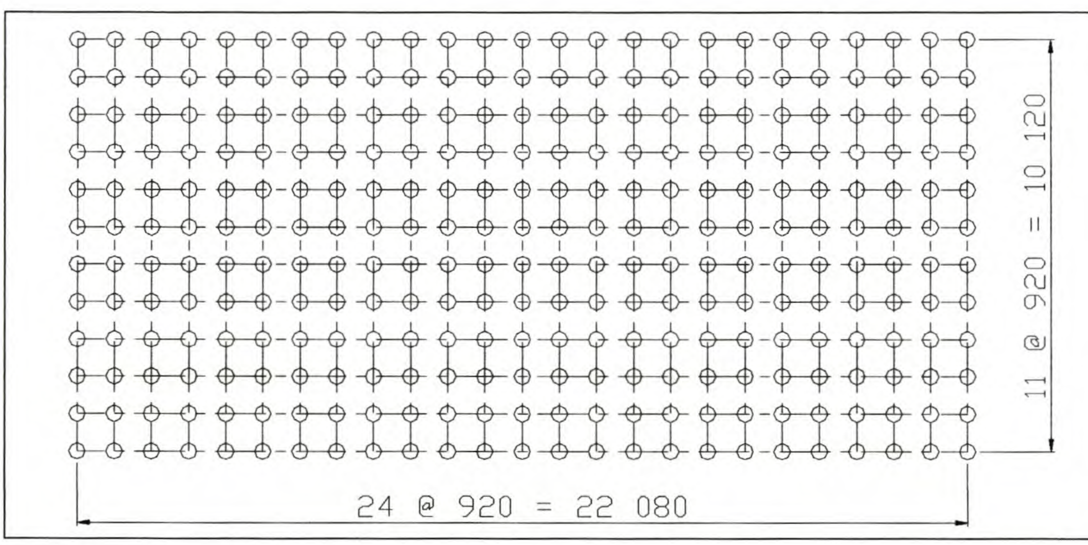


Figure 1.1 Plan on Test Floor

Fixing any structure to the test floor can only be done at these discrete fixing points. This limits the length of test beams and loading position to a multiple of 920 mm.

A flexible Multi-purpose Beam Testing Apparatus (MTA) had to be developed, designed and build in order to optimise the main test floor and existing loading equipment of the Structures Laboratory and to ensure successful testing.

The testing apparatus must make provisions for various beam sizes (length, depth and height), loading arrangements, static and kinematic boundary conditions without making major alterations to the setup.

The aim in using this multi-purpose beam testing apparatus is to reduce the cost of setting up, the materials used and the time spent, resulting in lower expenses in testing beams and making it more viable for product development and research testing.

The objective of the apparatus is to perform tests on various structural elements (although it is mainly aimed at testing beams), in order to assist with educating graduate students and furthering research by providing a testing apparatus that will comply with all testing requirements. The apparatus also needs to accommodate commercial testing and product development.

To ensure a useful or successful experiment, the test sample should be correctly prepared and the static and kinematic boundary conditions and data collection points correctly set up. The test also needs to be performed by a competent person, understanding structural and experimental mechanics, to ensure correct visual observations are made. For this reason an overview on testing and a testing procedure needed to be given.

The final objective of this thesis is to use the Multi-purpose Beam Testing Apparatus to perform various beam tests in order to evaluate the developed testing apparatus.

2 LITERATURE STUDY

2.1 Introduction

Testing a beam or a column, similar to testing other structural components, will require a test sample, a test arrangement and a method of test data acquisition. The test sample having unique properties, such as geometric and material properties, is set up in a test arrangement. Each test arrangement consists of two separate, but dependant, parts namely the boundary conditions and a loading arrangement. The third part of testing would be the collecting and the processing of the test data. The class diagram for a beam/column test is illustrated in Figure 2-1.

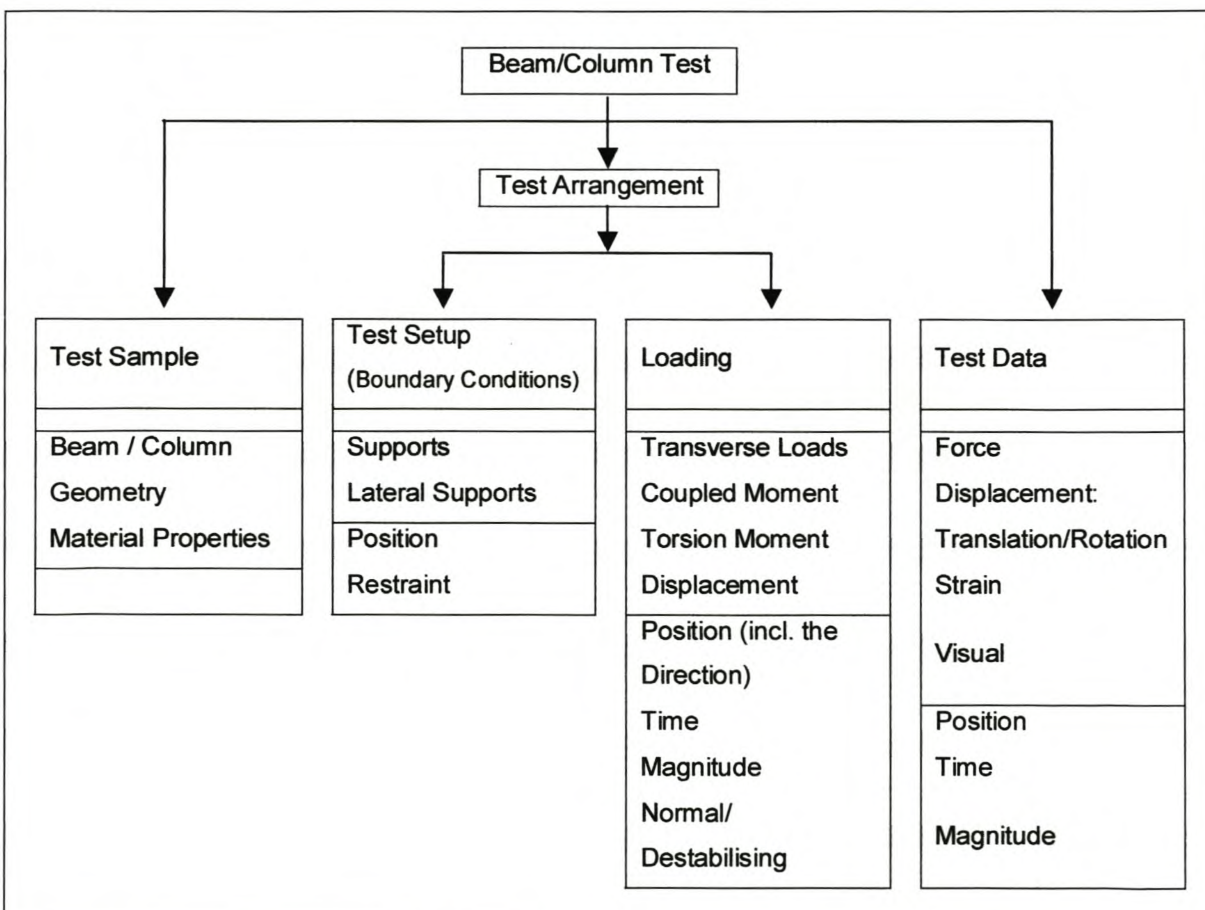


Figure 2-1 Class Diagram for Beam/Column Tests

This section will provide a brief overview of beam/column testing, with specific reference to Figure 2-1, under the following headings:

- Test Sample
- Test Arrangements
- Test Data Acquisition and Data Processing
- Frequently Used and Standard Test Setups

2.2 Test Sample

The structural member, such as a beam and/or column undergoing testing, is referred to as the test sample. The Test Sample forms the starting point of structural testing. The selected Test Sample needs to be statistically representative if a single sample is tested from a group. This section will focus on the definition of beams and columns, and at the inherent (geometric and material) properties of a test sample.

2.2.1 General Beam/Column Definitions

A beam and a column will be defined in the way they will act structurally, due to forces acting on them, rather than the dictionary definition of a beam being a "long sturdy piece of squared timber or metal spanning an opening or room, usually to support the structure above" and a column as "an upright cylindrical pillar supporting an entrance or arch."

A beam can simply be defined as a structural element resisting the forces acting on it in bending. This will result in a shear force and a bending moment acting along the length of the member. A beam can be in uni- or bi-axial bending, or in other words, bending about one or both cross sectional axes. A good example of a beam would be a crane girder spanning between crane columns. A gable column is also an example of a beam; in this case resisting wind loading, bending between the roof and the footing.

A column, on the other hand, can be defined as a member resisting axial (tension or compression) forces. Reinforced concrete columns in a braced concrete framed structure and bridge piers are good examples of columns.

A beam-column will act simultaneously as a beam and a column. This implies that the structural element will be in axial compression (or tension) and bending (uni-or bi-axial bending) simultaneously. Typical examples of such an element would be the columns of a portal frame.

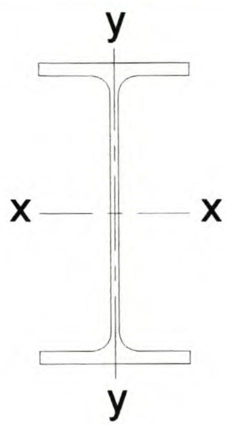
Torsion can be applied on both columns and beams. This will however not affect the element being a column or a beam as the torsion moment will be about the centroid of the element.

Structural elements, such as trusses can be formed out of columns and beams. In the case of the truss it will consist of a series of compression and tension members. Other examples of such structural element include the vierendeel frame and the portal frame.

Trusses will behave in a similar manner to a beam resisting bending. For this reason testing trusses can be considered the same as testing beams.

2.2.2 Geometry

Each test sample will have geometric properties. This includes the overall geometry, size (length and mass) of the sample and cross sectional properties. The cross sectional geometry will enable one to calculate the area, the moment of inertia about the xx and yy axis, and torsional properties of the cross section. The cross sectional properties for an IPE 200 are given as an example in Figure 2-2.



Section Description: IPE 200

$m = 22.4$ kg/m	$r_1 = 12$ mm
$h = 200$ mm	$h_w = 159$ mm
$b = 100$ mm	$A = 2\ 850$ mm^2
$t_w = 5.6$ mm	$J = 70.2 \times 10^3$ mm^4
$t_f = 8.5$ mm	$C_w = 13.1 \times 10^3$ mm^6
About x-x	**About y-y**
$I = 19.4 \times 10^6$ mm^4	$I = 1.42 \times 10^6$ mm^4
$Z_e = 194 \times 10^3$ mm^3	$Z_e = 28.5 \times 10^3$ mm^3
$Z_{pl} = 221 \times 10^3$ mm^3	$Z_{pl} = 44.6 \times 10^3$ mm^3
$r = 83.6$ mm	$r = 22.4$ mm

Figure 2-2 Cross Sectional Properties: IPE 200 [1]

2.2.3 Material Properties

Test samples of different materials will behave differently under the same test due to the difference in material properties. For this reason it is important to have representative material samples (coupons form the test specimen) tested of each test sample so that the material properties can be determined. A weighted average method can be used to compute the average material strength in the case of I-beams as coupons taken from the flanges and webs will yield different results [21].

Material behaviour will include elastic, elastic plastic, plastic, strain hardening, strain aging, yield and fracture. These properties can vary for compression and tension forces and with temperature. A typical stress/strain graph for steel is illustrated in Figure 2-3.

Material properties together with geometric properties will enable one to use test results to verify analytical assumptions and derive design equations for the specific member.

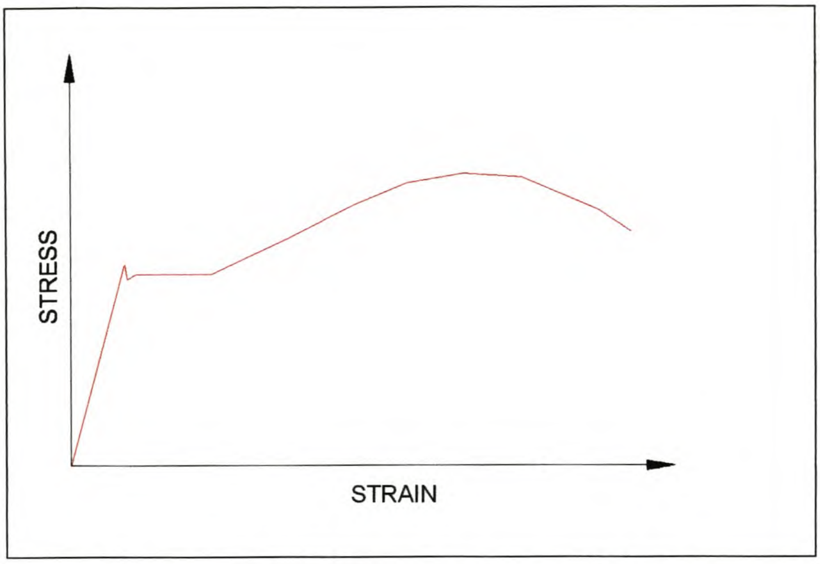


Figure 2-3 Typical Stress Strain Graph for Steel [1]

2.3 Test Arrangement

The test arrangement refers to the way the test sample is "set up" for testing. The setup of the specimen can be separated in two separate, but co-dependant items, namely the position and type of supports (static and kinematic boundary conditions) and the loading type and arrangement thereof.

This section will take a closer look at the static and kinematic boundary conditions for testing beams and columns and at the various loading types and loading arrangements.

2.3.1 Static and Kinematic Boundary Conditions

Static and kinematic boundary conditions are either required for equilibrium or stability conditions (or both) when testing a column or beam and will determine the behaviour of the column or beam under a specific loading condition. By changing the boundary conditions the structural response of the element will change, as the boundary condition will influence the effective length of the test sample.

A good example of altered structural behaviour due to changing static and kinematic boundary conditions would be to provide (stability) lateral support to a beam failing due to lateral torsional buckling. By doing this, the moment of resistance of the beam will be increased and could even result in a different failure mode.

The kinematic and static boundary conditions at the end of the span of a beam or at the ends of a column provide some to no support (rotation or translation) about the main axis of the beam or columns and are generally referred to as end supports, span supports or just as supports. Secondary supports are referred to as lateral support as it will provide support about the secondary axis of the beam or column. The symbols for each type of restraint are given in Figure 2-4.

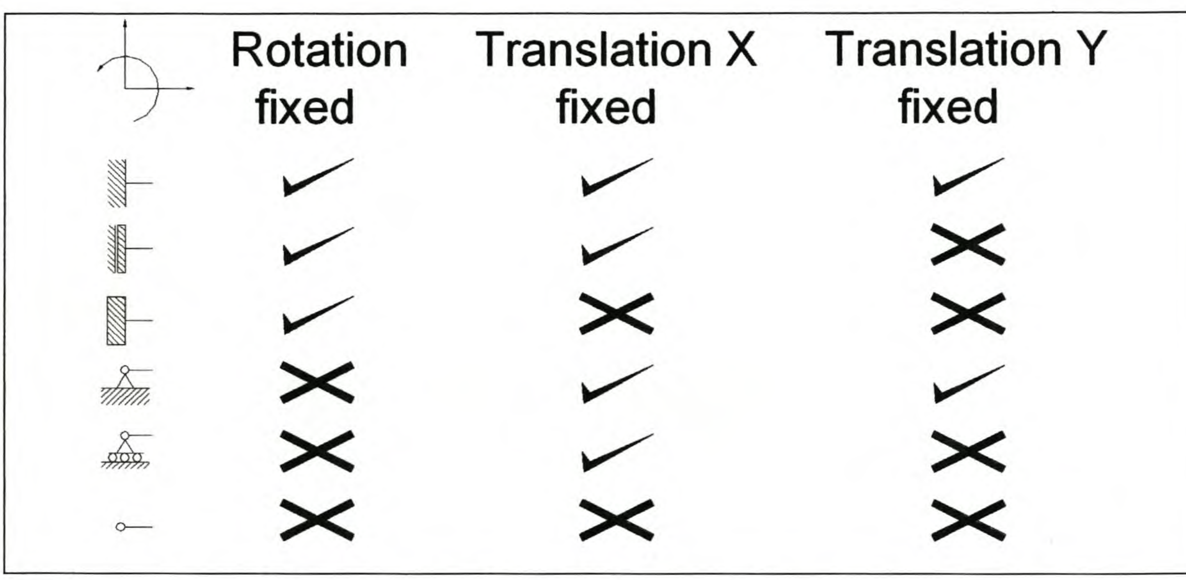


Figure 2-4 Symbols for Restraint Provided at Supports [1, 2]

Generally a beam or column end is described as fixed if full restraint is provided against rotation and translation. A pinned support is where restraint is only provided against translation. An end with no restraint is known as a free end.

Boundary restraints need to provide both stiffness and force [24], as will be illustrated later, and provide for overall equilibrium and stability to the test sample.

An elastic support or boundary condition can be defined as a boundary condition with insufficient stiffness. In such a case the "desired imperfection" of the boundary condition will result in a deflection or rotation at the support that will influence the test results.

Practically, providing a perfect fixed or free restraint is not possible. However the forces and deflections involved in beam tests are of substantial higher order compared to the forces and deflections caused due to the imperfection of commonly used supports (i.e. the stiffness of the support is much greater than the stiffness of the test piece). For this reason the imperfections of the supports are ignored.

A further attribute of the test set-up would be the position of the boundary conditions. The position of these restraints will define the span (length) of a beam, thus the span (length) of a beam is taken as the distance between the centres of the supports. The span length can be compared to he effective length of a beam that takes the type of restraint into account. This will be discussed in more detail in the following sections.

2.3.1.1 End/Span Support

The supports will have to provide primary restraint against the main forces acting on the beam in order to prevent a mechanism or unstable structure during testing. The translation in the case of a pinned, and rotation in the case of a fixed support should be nominal during a test in order to prevent the imperfection of the support influencing the outcome of the test. This is usually the case. However with a fixed end support, as would be the case of testing cantilevers, the rotation of the support should be measured in order to rectify the measured deflections.

The position, number of, and restraints at the supports will determine the test setup. This is illustrated in Figure 2-5 and Figure 2-6. As an example, a beam with two supports will only have a single span. If this beam has no rotation restraints at the supports, the beam would be simply supported. Similarly a beam with two supports of which one is set up as free, can only be a cantilever [1].

Overhung ends will only affect the test set-up if loading is applied at the overhang end. If loading is applied only within the span and not at the overhung end, the beam will behave as if the overhung was a normal pinned support.

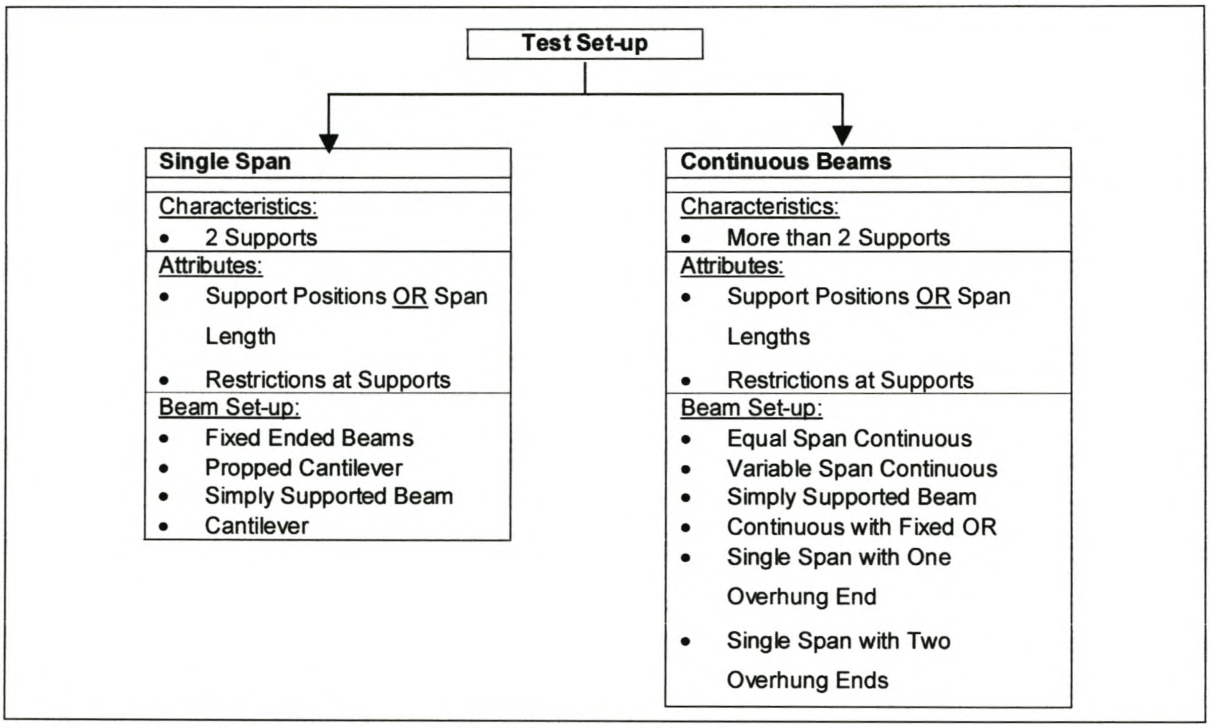


Figure 2-5 Class Diagram for Beam Test Set-up

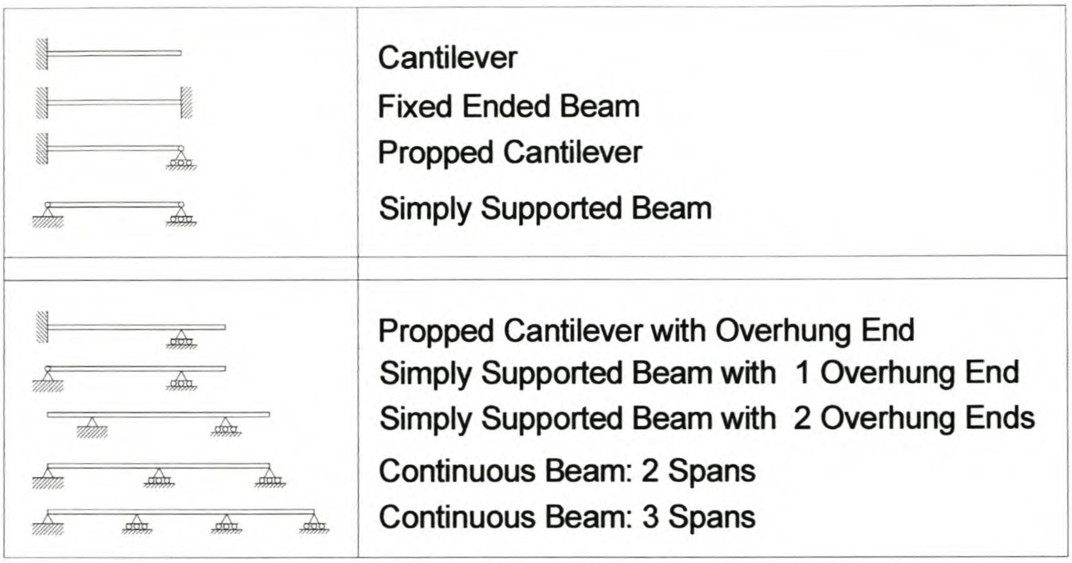


Figure 2-6 Typical Beam Test Set-ups [1]

The position of the supports will determine the span (length) of a beam. The span (length) of a beam is measured as the distance between the centres of the supports. The span length does not take any rotational restraint the support might provide into account. The effective length would take restraints at the support into account.

<u>2.3.1.2</u> <u>Lateral Support</u>

Lateral supports, as for end/span supports, are either required to provide equilibrium or stability restraint about the secondary axis of the beam. The restraint can either restrict the rotation and or translation of the test sample at the bracing point and will prevent out of plane movement [3, 4]. Although lateral supports are usually required at the supports and loading positions, the positions of the lateral supports are independent of the end supports and loading positions. Providing lateral support or support about the one axis of a beam should not effect the loading about the other axis.

For uni-axial bending the lateral supports are only required to provide stability to the compression face of the beam. This will prevent the lateral translation and rotation (i.e. lateral torsional buckling) of the beam and can be referred to as stability lateral supports.

Bi-axial bending of the beam and torsion will however require the lateral supports to resist substantially larger forces compared to uni-axial bending to ensure the equilibrium of the test sample. Equilibrium equations should be used to calculate the forces the lateral supports are required to resist. The stiffness the lateral support needs to provide, as for supports (in order to provide sufficient restraint), can then be calculated. In such a case the lateral supports can be referred to as equilibrium lateral supports.

Stability lateral supports need to provide both force and stiffness and are used for beams columns and frames. It reduces the effective length of columns and unsupported length of beams and provides overall stability to frames. Lateral support can either be at discrete points along the test sample or continuous [24].

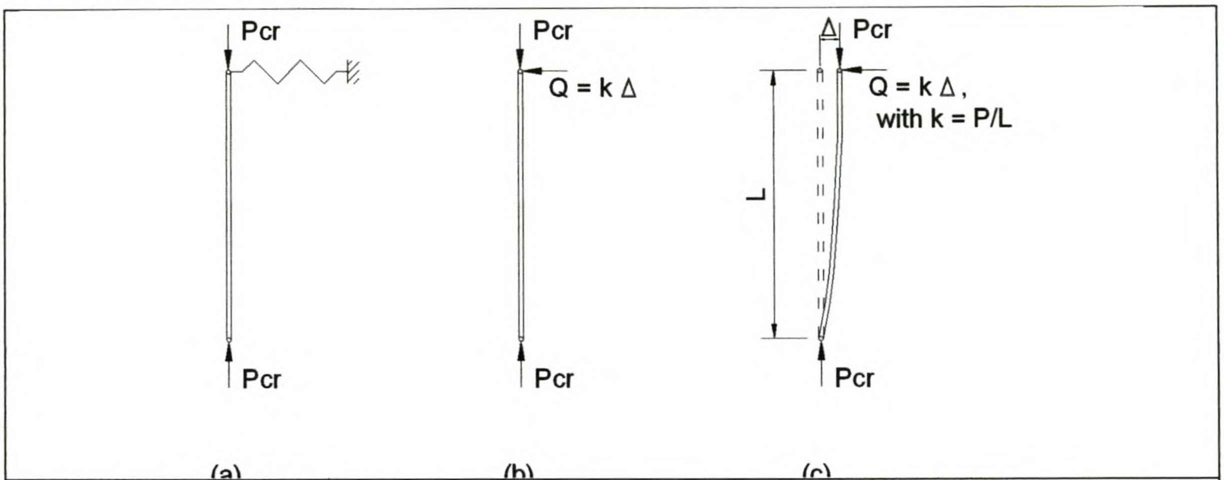
As an example, if bracing is provided to a column as indicated in Figure 2-7, the force required to brace the column (Q) would be zero if the deflection (Δ) is zero. This would only apply in ideal circumstances as indicated in (b). For less than ideal circumstances as indicated in (c);

$$Q = k\,\Delta.$$

And from equilibrium equations the required bracing stiffness, $k = P/L$,
where P is the compression load in the column, and Δ is defined in Figure 2-7.

If $k\,\Delta L > P\,\Delta$, no side sway will occur, and if $k\,\Delta L < P\,\Delta$, side sway will occur. The critical case happens when $k_0\Delta L = P\,\Delta$, where k_0 is the minimum stiffness required to brace the system and is referred to as the critical stiffness.

From the above example, assuming zero initial deflection i.e. ignoring initial crookedness $k_0 = P_{cr}/L$. If $k/k_0 > 1$, the system can be considered as braced if P_{cr} can be reached. If $k/k_0 < 1$ the system is partially braced as $P/P_{cr} < 1$ as can be seen from Figure 2-8.



k = spring stiffness [N/mm]

P_{cr} = Maximum Compression Load [N]

(for slender columns; $P_{cr} = C_e$ = Euler buckling strength = $\pi^2 EI/L^2$)

Δ = deflection [mm]

Figure 2-7 A braced column (a), ideally no side sway (b), and less than ideal with side sway (c) [24].

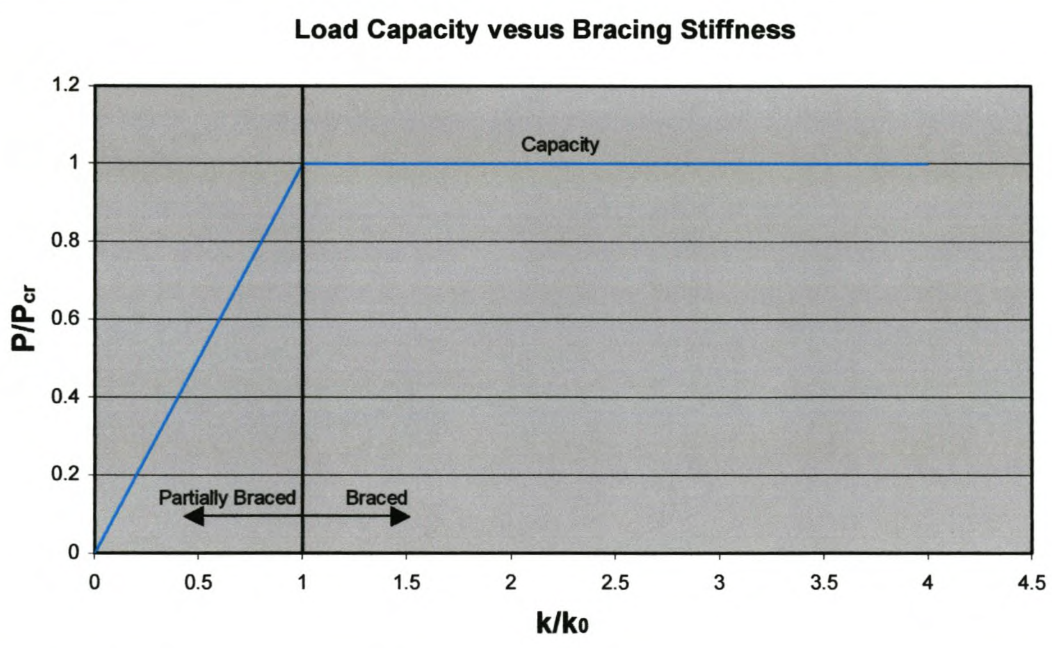
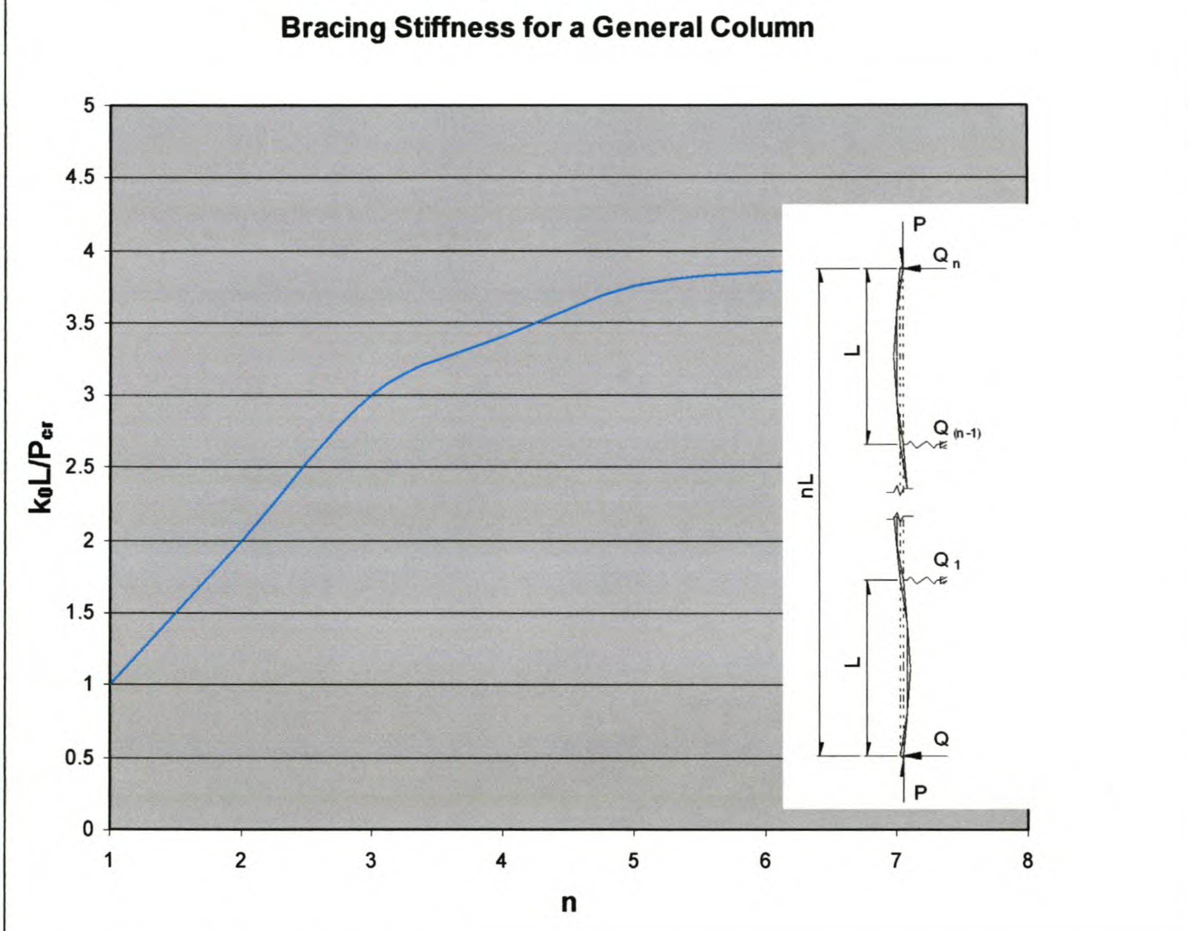


Figure 2-8 Load Capacity versus bracing stiffness

Providing bracing of stiffness greater than the critical stiffness ($k/k_0 > 1$) has no value in increasing the load capacity of the above column. For a general braced column the bracing stiffness is plotted in Figure 2-9.



In general $k_0 = \beta P/L$, with $\beta = k_0L/P_{cr}$

Figure 2-9 Required Bracing Stiffness for a General Column

In a real structure or test setup columns (and beams) have initial crookedness or deflection (Δ_0), and that stabilizing forces in the bracing system only occurs when the forces in the column cause the bracing to deform. Typical tolerances for compression members are 1/500 to 1/1000 of the span of the length of the member for plumbness. For the example in Figure 2-7 the critical bracing force is increased; $Q = k_0(1+ \Delta_0/\Delta)\Delta$..

Using the above relationship the ratio of bracing stiffness to critical bracing stiffness (k/k_0) and bracing force to critical bracing force ($Q/\Delta_0 k_0$) can be plotted to the deflection to initial deflection relationship (Δ/Δ_0) as indicated in Figure 2-10.

As the stiffness of the brace (k) increase the deflection (Δ) decreases. If the stiffness decreases, the required bracing force (Q) increases, therefore bracing needs to be designed for both stiffness and force. If the bracing stiffness is equal to the critical bracing stiffness ($k/k_0 = 1$), the deflection tends to infinity ($\Delta \rightarrow \infty$). Ideally to brace a structure the ratio of bracing stiffness to critical bracing stiffness needs to be greater than two ($k/k_0 > 2$).

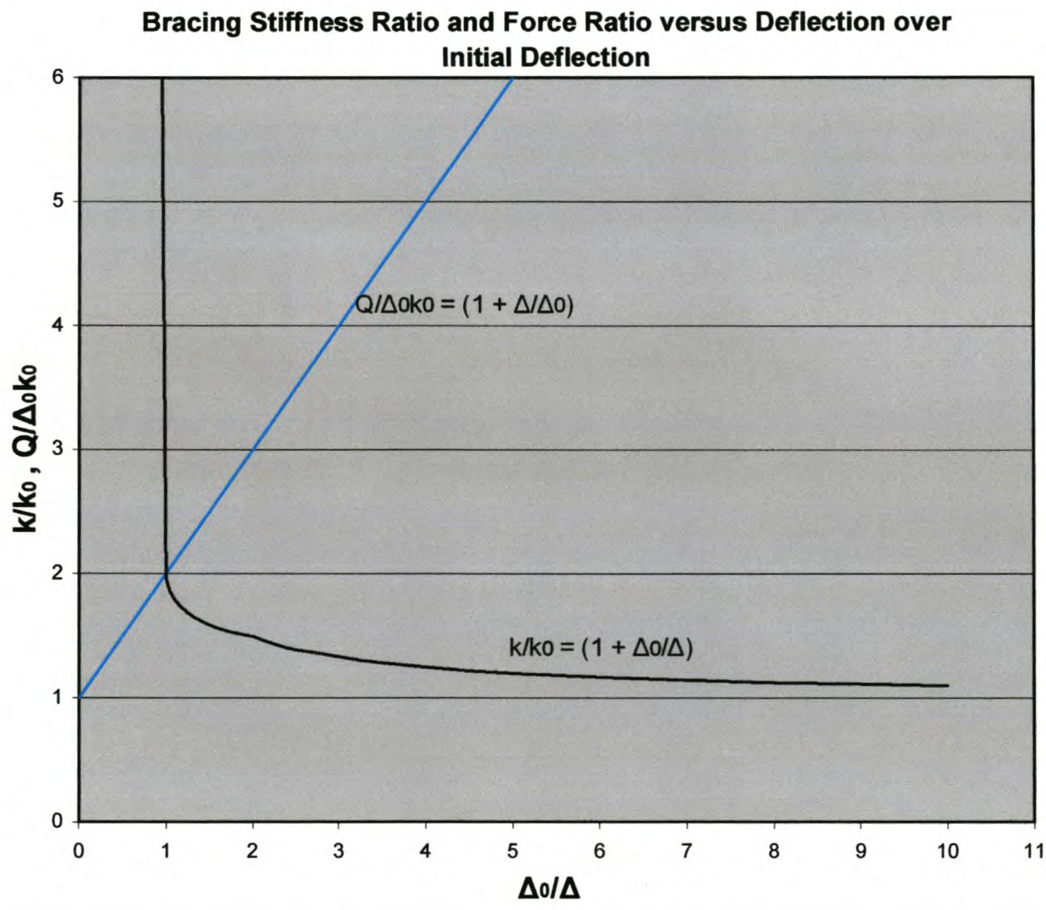


Figure 2-10 Bracing Stiffness Ratio and Force Ratio versus Deflection over Initial Deflection

To design a brace using the stiffness approach, the deflection of the brace is assumed to be equal to the initial deflection, and the initial deflection assumed to be less than L/500, the required bracing force becomes then becomes:

$Q = 0.004\beta P_{cr}$,

where P_{cr} is the compression force in a column or the flange of a beam in bending. Using Q, a bracing member can be designed, and the axial displacement calculated. The required bracing force can then be recalculated till the assumed deflection of the bracing is equal to the calculated deflection [24].

In the case of a steel beam or column, SABS 162: 1-1993 [2] will require the lateral support to provide a force of 1% of the force in the compression flange of the beam or column in bending or compression.

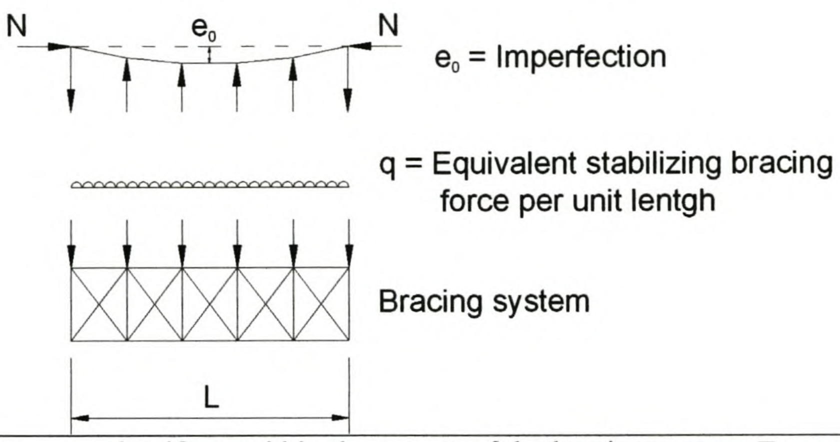
Eurocode 3 [25] requires an equivalent stabilizing bracing force of q per unit length of the member as indicated in Figure 2-11. Where a bracing system is required to brace a beam, the force in the beam, N, are taken as:

$$N = M/h,$$

where M is the maximum moment in the beam

and h is the overall depth of the beam.

In Table 2.1 the factored required bracing force for an IPE 200 column of various slenderness ratios and number of bracing points is given as required by SABS 162: 1-1993 [2], Eurocode 3 [25] and the stiffness approach [24]. For a single brace and for the allowable in-plane deflection of less than span/2500 ($\Delta \leq L/2500$) SABS 162 and Eurocode 3 give the same values. The Eurocode however allows for the reduction of the bracing force if the number of bracing points is increased. Both codes values are conservative for $\Delta/L < 2500$ for all beam lengths.



The force N is assumed uniform within the span L of the bracing system. For non-uniform force this is slightly conservative.

$e_0 = k_r L/500$

where e_0 is the imperfection

L is the span of the bracing system

and k_r = $[0.2 + 1/n_r]0.5$ but $k_r \leq 1.0$

in which n_r is the number of members to be restrained

<u>For a single restrained member:</u>

for $\delta_q \leq L/2500$: $q = N/50L$

for $\delta_q > L/2500$: $q = N/60L\ [1+a]$

where δ_q is the in-plane deflection of the bracing system due to q plus external loads

and a = $500\ \delta_q/L$ but $a \geq 0.2$

<u>For multiple restrained member:</u>

for $\delta_q \leq L/2500$: $q = \sum N/60L\ [k_r + 0.2]$

for $\delta_q > L/2500$: $q = \sum N/60L\ [k_r + a]$

Figure 2-11 Equivalent stabilizing bracing force as required by Eurocode 3 [25].

Slenderness (KL/r)	50		100		200	
C_r (kN)	642.5		361.5		118.8	
Bracing Force (kN)						
Δ/L	1/2500	1/500	1/2500	1/500	1/2500	1/500
SABS 162: 1-1993 (for all values of n)	6.42		3.61		1.18	
Eurocode 3						
n = 2	6.42	10.71	3.61	6.02	1.18	1.98
n = 3	4.28	7.14	2.41	4.02	0.79	1.32
n = 4	3.21	5.35	1.81	3.01	0.59	0.99
$Q = 2(\Delta/L)\beta P_{cr}$						
n = 2	1.03	5.14	0.58	2.89	0.19	0.95
n = 3	1.54	7.71	0.87	4.34	0.29	1.43
n = 4	1.61	8.07	0.91	4.54	0.30	1.49
Column Length = nL (as indicated in Figure 2-9) C_r = factored capacity of column Δ = in plane deflection Assumed $\Delta_0 = \Delta$						

Table 2.1 Required Bracing forces for an IPE 200 Column for Various Slenderness Ratios

For more than one brace, the bracing force becomes less conservative as the Δ/L value increases. The bracing force as given in SABS 162 correspond to the initial value of the stiffness approach for n > 4 if $\Delta_0 = \Delta = L/800$ is assumed.

In practice SABS 162 tends to be conservative compared to the stiffness approach [24]. It however does not allow for a variance in initial imperfections and gives no indication of the expected in plane deflection of the bracing system.

Eurocode allows for initial imperfections and the number of restraints to be taken into account in the calculation of the bracing force. If the span of the beam is increased corresponding to the number of restraints, such as the example in Table 2.1, it tends to be unconservative for $\Delta/L > 1/1000$.

In experiments all three of the above approaches can be used to calculate the bracing force. The stiffness approach is however highly recommended, as it will give an indication of deflection of the bracing system and allows for a variation of initial imperfections.

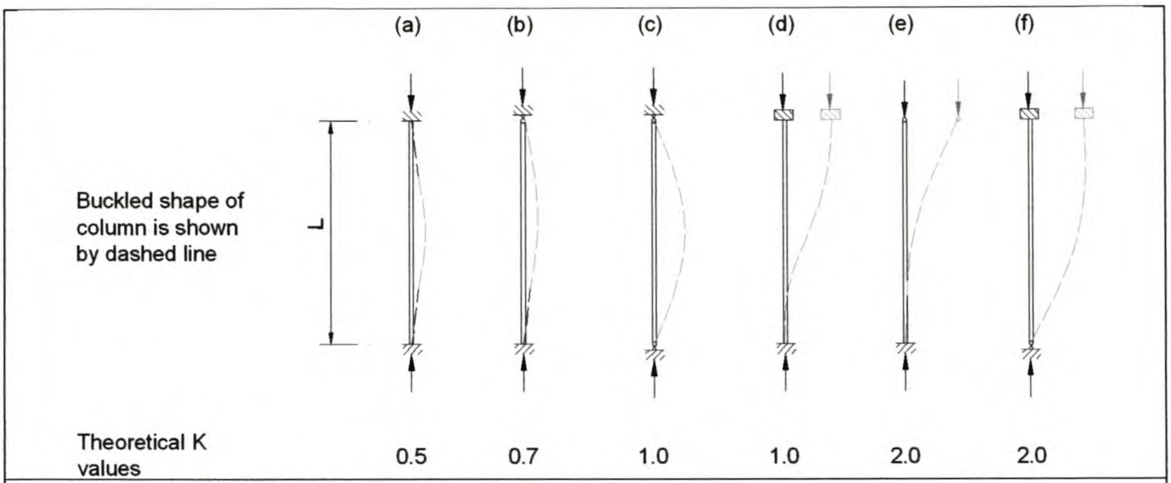
It is recommended to monitor the lateral deflection of the bracing system during experiments to ensure that the deflection is within limits if stiffness calculations are not performed.

In the design of columns and beams an effective length factor, K, is usually used to make provisions for kinematic and static boundary conditions of the element in question.

The effective length (KL) of a column or beam will reflect the "true length" of the element and reflects the impact of the boundary condition on the test result. In the case of the column this length would correspond to the length between inflection points. The theoretical effective length factors for a column are given in Figure 2-12. (Note that the Euler equation as given above only applies for the failure of columns in the elastic buckling zone. Other failure modes include local buckling, torsional buckling, inelastic buckling and the reaching of the yield stress, for steel columns.)

The same principal of effective length applies to beams. For double symmetric beams, assuming small deflection theory, no axial force, no cross-sectional distortion, Hookes Law, prismatic straight members, no twist or displacement at the supports, in-plane loading and a constant moment across the beam the differential equations for torsion and flexure can be used to determine the elastic buckling moment for a beam as:

$$Mcr = \pi / L \sqrt{EI_yGJ + (\pi^2E^2/L^2)C_wI_y} \quad [26, 27]$$



K = effective length factor

C_e = Euler buckling strength = $\pi^2 EI/(KL)^2$ [N]

Figure 2-12 Effective lengths of compressive members [1, 2, 26]

In the case of lateral torsional buckling not only the boundary conditions influence the elastic torsional buckling load but also the loading on the beam. As for above case the differential equations for torsion and flexure can be used to determine the elastic buckling moment in varied cases. These equations are usually solved using numerical methods as we can only solve for the simplest cases. The effective length concept is imported in determining the design elastic buckling moment. It is either done by two effective length factors (K_y: lateral effective length factor, K_z: torsional effective length factor) or by means of a single effective length factor (K) [26]. Additional factors allowing for the type of loading are also added to the buckling equation. Exact effective length values can be found in [26].

For non-linear elastic behaviour (for materials such as fibre reinforced plastics) the flexural-torsional and lateral-distorsional buckling responses can be derived [27].

For research purposes the buckling equations and effective length values as given in SABS 162: 1-1993 [2] are conservative, but will however give an good indication on the influence of boundary and loading to the lateral torsional buckling strength of the beam.

Buckling equations given in SABS 162: 1-1993 [2]:

$$M_{cr} = \frac{\omega_2 \pi}{KL} \sqrt{E I_y G J + (\pi E / KL)^2 C_w I_y}$$

As an example SABS 162 requires the effective length of a beam to be increased by 20% if the end are not restrained against torsion. (Note that the lateral torsional buckling of beams was only described to illustrate the influence of boundary conditions on the effective length of a beam. Other failure modes would include a plastic hinge, flange local buckling, web local buckling, web plastification and web buckling, for steel beams.)

The ideal bracing system, taking all the above into consideration, will vary depending on the test sample, the test setup and the loading. The four methods most commonly used to provide lateral restraint in experiments includes the Watt mechanism, guide tracks, rods and cables. These methods will be discussed in more detail and specific reference will be made of the advantages and disadvantages of each method.

Watt Mechanism [5]

This lateral bracing system is designed on the principals of the "Watt's straight-line mechanism" and illustrated in Figure 2-13. The Watt's mechanism consists of two levers. Each one of these levers is supported at one end and connected to a coupler at the other. All connections are pinned, and the two levers can have different lengths. In the undeflected shape the two levers will be parallel.

In the Watt's geometry, there is a point E on the centre line of the coupler that traces an approximate straight line within certain limits as the mechanism is deflected. When the two levers are equal, E is at the centre of the coupler. This locus of E is very close to a straight line up to a point O. The locus of E and the point O can be determined graphically or analytically. The distance EO is defined as the stroke of the mechanism, with the total straight-line motion (ON) being twice the stroke, since the linkage can work both ways.

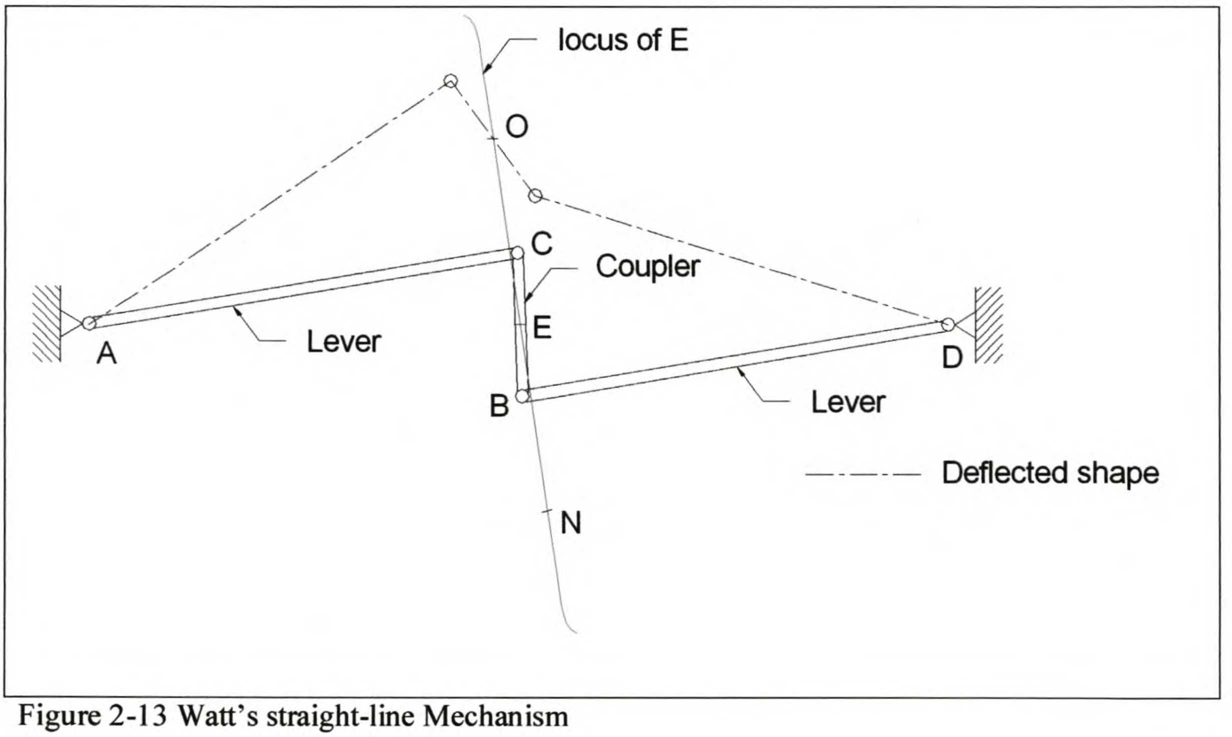


Figure 2-13 Watt's straight-line Mechanism

The two dimensional properties of the Watt mechanism can be extended into three dimensions by introducing a ball-and-socket joint in place of the pinned joints. This will allow point E, also referred to as the braced point, to form a vertical locus similar to that formed in two dimensions, preventing out of plane (lateral) motion of the point. The use of the Watt mechanism to provide lateral support is shown in Figure 2-14.

The biggest advantage of the Watt mechanism is that this bracing system requires no manual adjustments during testing in order to prevent restraining forces. This system also allows for large deflections of the test specimen. The Watt mechanism is fixed to the structure at a point E, as indicated in Figure 2-13, and will provide lateral restraint to that point.

The disadvantages of the system are that it cannot be used to apply lateral loading and that the weight of the mechanism will apply an extra dead load on the test specimen. This load is small compared to applied load on the test specimen and can usually be ignored.

Figure 2-14 The Watt Mechanism Used to Provide Lateral Support

Guide Tracks

This lateral restraining mechanism consists of guides, or movement tracks directing the allowable deflection or movement and preventing the out of plane deflection and movement of the test specimen.

The test piece is either fitted closely between two guiding elements, as indicated in Figure 2-15, or can be fixed to one of these guides so that only a single guide will be required. The guide tracks are fixed to pinned supports, ensuring that no dead load would be placed on the test specimen.

The tracks prevent the out of plane movement of the entire section at the bracing point, making it ideal for testing beams where bracing is required against lateral torsional buckling. The use of guide tracks to prevent lateral torsional buckling is shown in Figure 2-16.

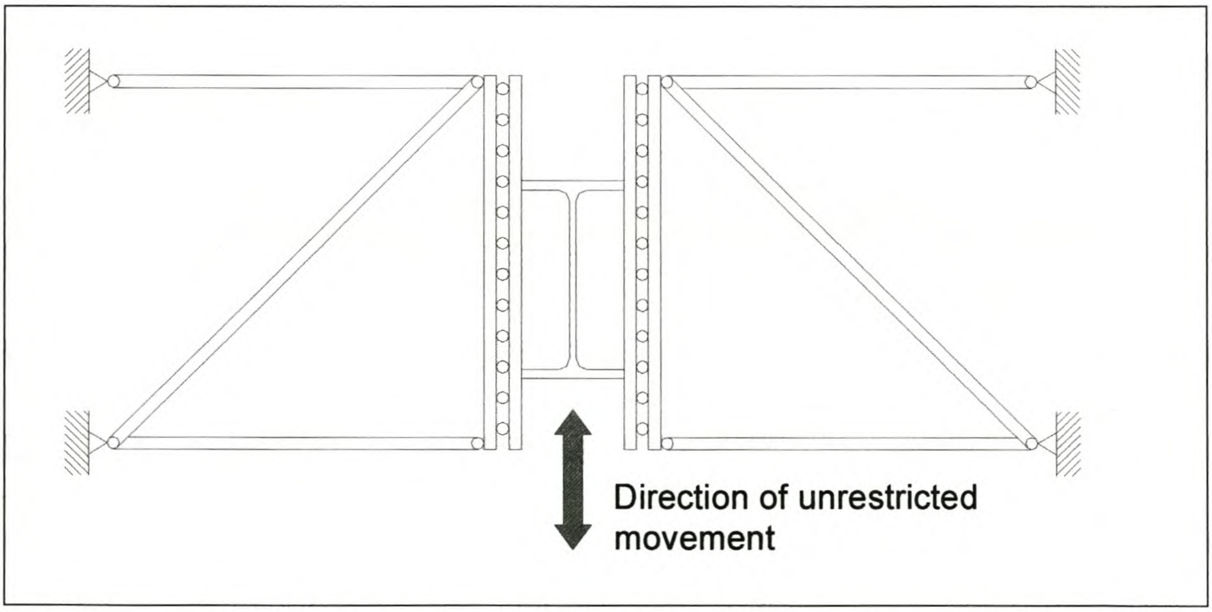


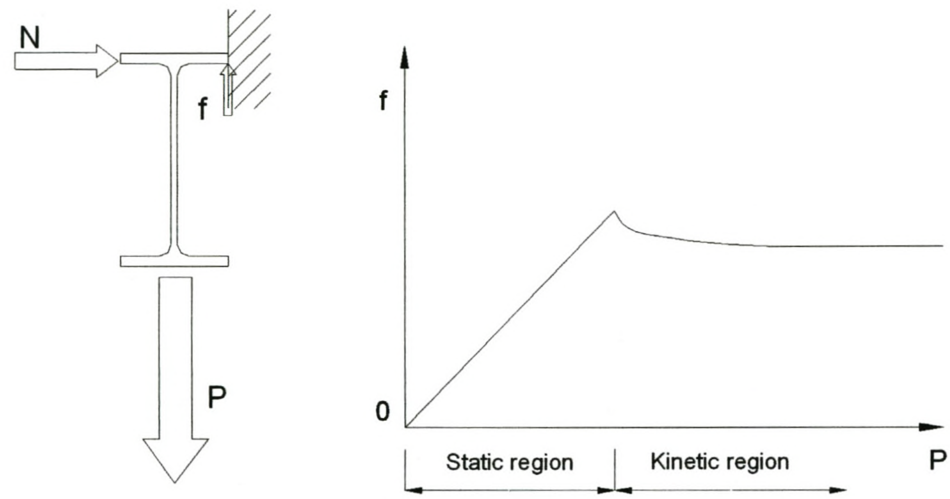
Figure 2-15 Using Two Guide Tracks to Provide Lateral Support

Figure 2-16 Guide Tracks Used as Lateral Support

Guide elements can also be used to apply lateral loading and will allow for large deflections of the test sample without the need for manual adjustments during testing.

The biggest disadvantage of guide tracks is that this lateral bracing system will require to be adjusted for different specimens. After each test guide tracks needs to be aligned to ensure that the desired deflection plane is still correct.

Restricting forces are limited to the friction of the guide tracks. For most materials used in producing guide tracks, the friction coefficient is so small that the restricting force can be ignored. Typical (static and kinetic) frictional coefficients are given in Figure 2-17.



For static region: $f_s = \mu_s N$ (N)	For kinetic region: $f_k = \mu k_s N$ (N)	
Material	μ_s	μ_k
Steel on Steel	0.74	0.57
Aluminium on steel	0.61	0.47
Copper on steel	0.53	0.36
Wood on wood	0.25-0.5	0.2
Metal on metal (lubricated)	0.15	0.06
Teflon on Teflon	0.04	0.04

Figure 2-17 Static and kinetic friction coefficients for various materials [28].

Rods (/Strut)

This lateral supporting mechanism, as illustrated in Figure 2-18, consists of a compression (and tension) member (namely the strut or rod) pinned at a point A and connected to the test piece at a point B. This allows point B to form a circular locus. Provided the deflections (V) are small and the rod length long enough, the distance the locus varies form a straight-line (h), will also be small as can be seen in Figure 2-19. The locus of B was determined from simple geometry using:

$h = L(\sqrt{(L^2} + (V/2)^2) - L) / \sqrt{(L^2} + (V/2)^2)$,

where h is the horizontal deviation,

V is the total vertical deflection

and L is the length of the rod

Alternatively the locus of B can be determined graphically. The approximate straight-line distance (BC) is defined as the stroke of the mechanism, with the total straight-line motion (DC) as twice the stroke, since the rod mechanism works both ways. The length of the strut and the stiffness thereof should ensure that the deviation (h) from a straight line for a test do not exceed the $\Delta/L = 1/500$ ratio as discussed previously (where L is the span of the beam).

For large deflections manual adjustments will be required in order to prevent restraining forces. Without these adjustments the locus motion of point B will not only cause restraining forces on the test piece, but also lateral forces, causing bending about the secondary axis of the test piece. These adjustments can be made by either adjusting the length of the rod, or by adjusting the position of point A.

The biggest advantage of this system is the simple way in which it is set up and that it can be used to apply lateral forces on the test sample. The main disadvantage of this system is that it will require manual adjustments for large deflections as discussed above.

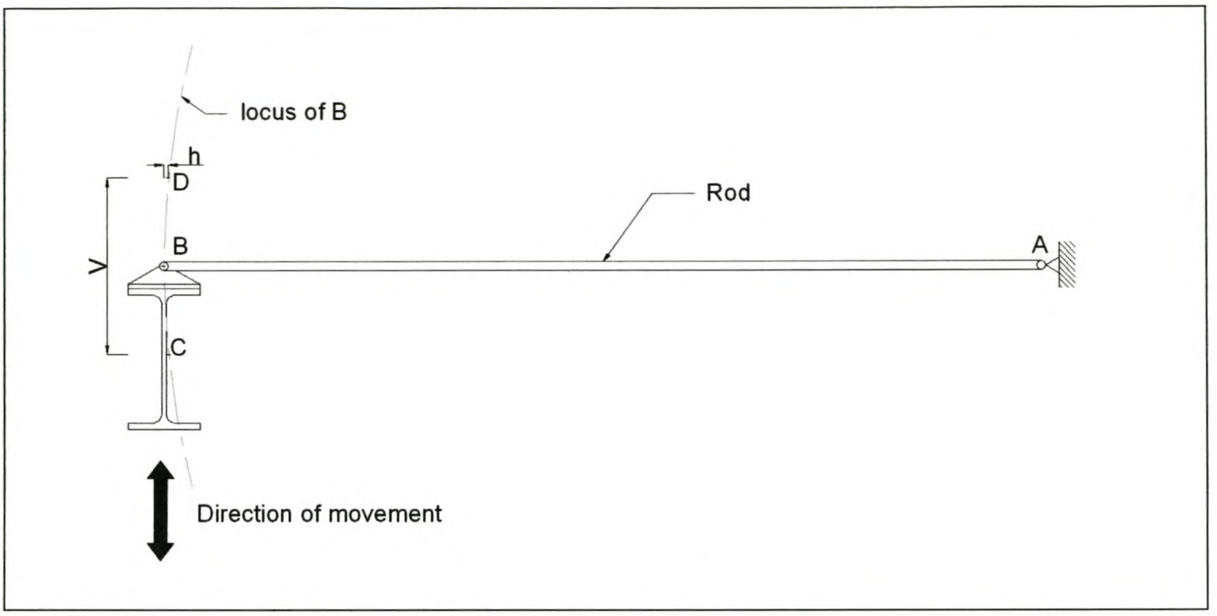


Figure 2-18 Using a Rod as Lateral Supporting Mechanism

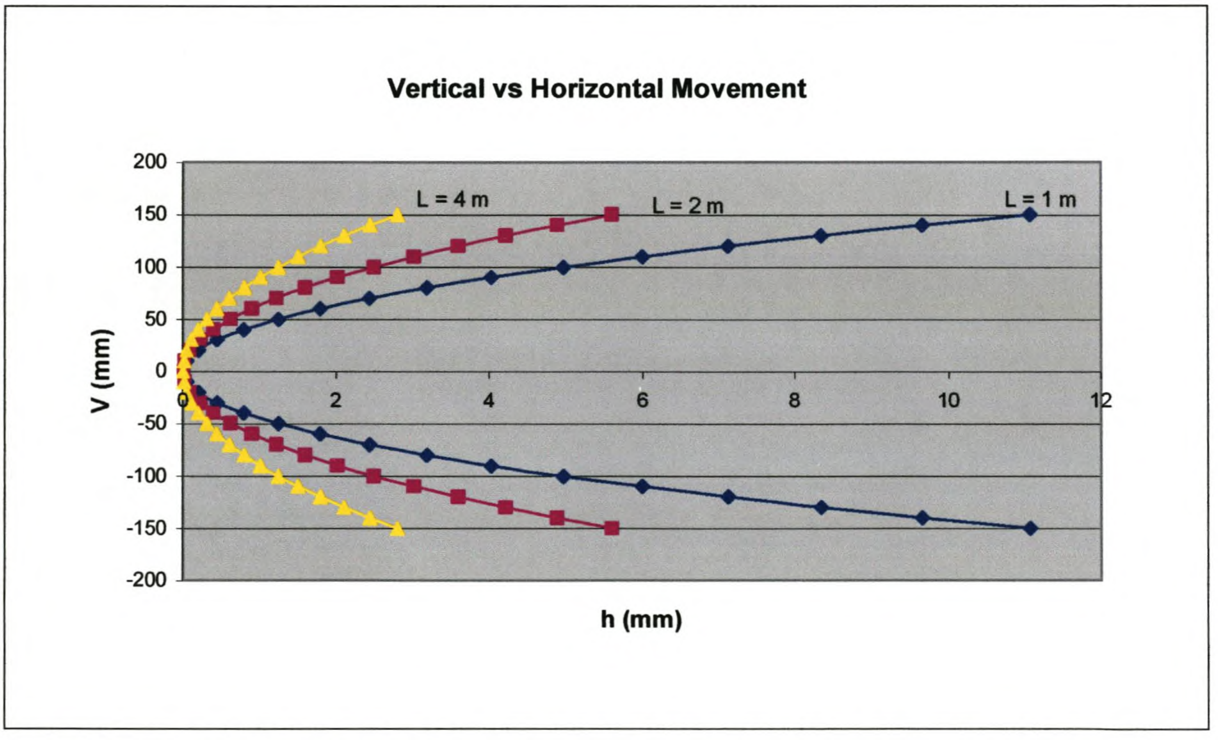


Figure 2-19 The Vertical Displacement versus the Horizontal Deviation to a Straight-Line Motion for Rods of various Lengths

Cables

Cables as lateral supporting mechanism are set up very similar to rods, as can be seen in Figure 2-20. A tension member (referred to as a cable) is pinned at a point A and connected to the test piece at a point B. A second cable is also connected to the test piece at point B and pinned at a point C, mirrored around the centre line of the test piece.

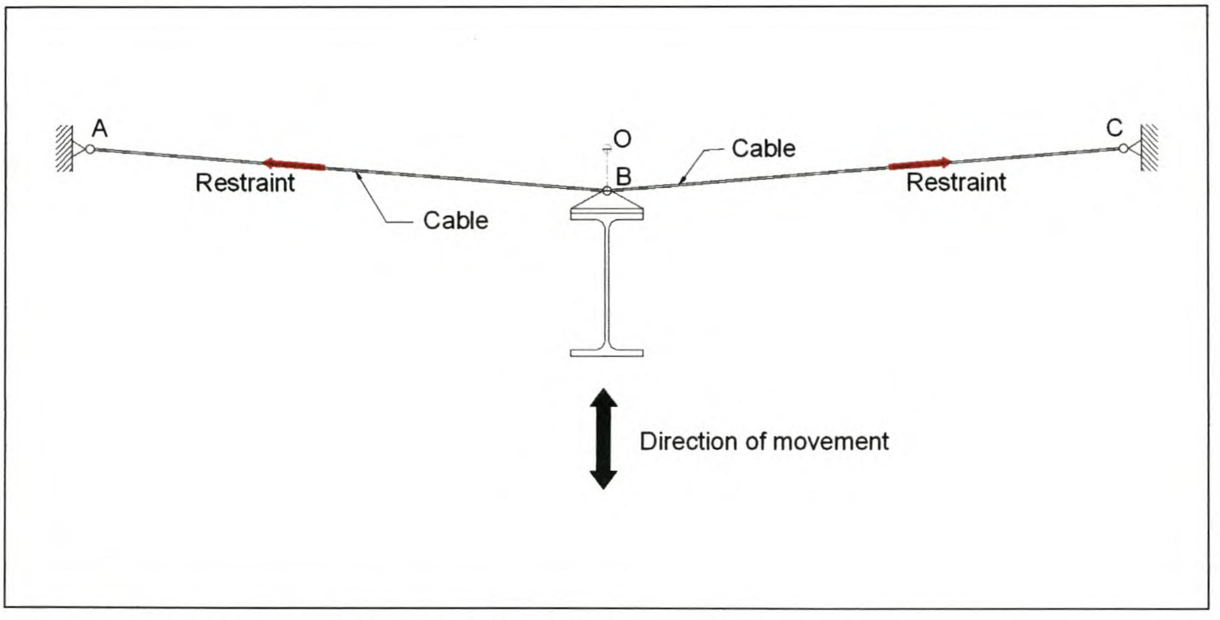


Figure 2-20 Using Cables as Lateral Support

The cable mechanism can be controlled in order to behave in the same way as a rod by ensuring that only the one cable is in tension, and the other cable acts only as a "safe guard" against force reversal. In this case Figure 2-19 would give an indication of the straight-line motion of the mechanism.

Using both cables, as illustrated in Figure 2-20, the locus of motion would be a straight line (OB) provided point A and C are mirrored about the centreline of the beam, and the stiffness of the two cables are the same. The cables will however produce restraining forces due to the lengthening of the cables as indicated in Figure 2-20. These restraining forces can be eliminated or minimised by manual adjustments during testing. These adjustments entail adjusting the cable length or simply keeping the cable horizontal by adjusting the position of point A and C.

Normally, due to the low stiffness of the cables, and small deflections (V), the restraining forces will be small (as can be seen in Figure 2-21) compared to the applied forces and are therefore usually ignored (In Figure 2-21 the restraining forces for a 6 mm diameter steel cable of various cable lengths are plotted on the secondary axis.).

The biggest advantage of this system is the simple way in which it is set up and that it can be used to apply lateral forces on the test sample. The main disadvantage of this system is that it will require manual adjustments for large deflections as discussed above.

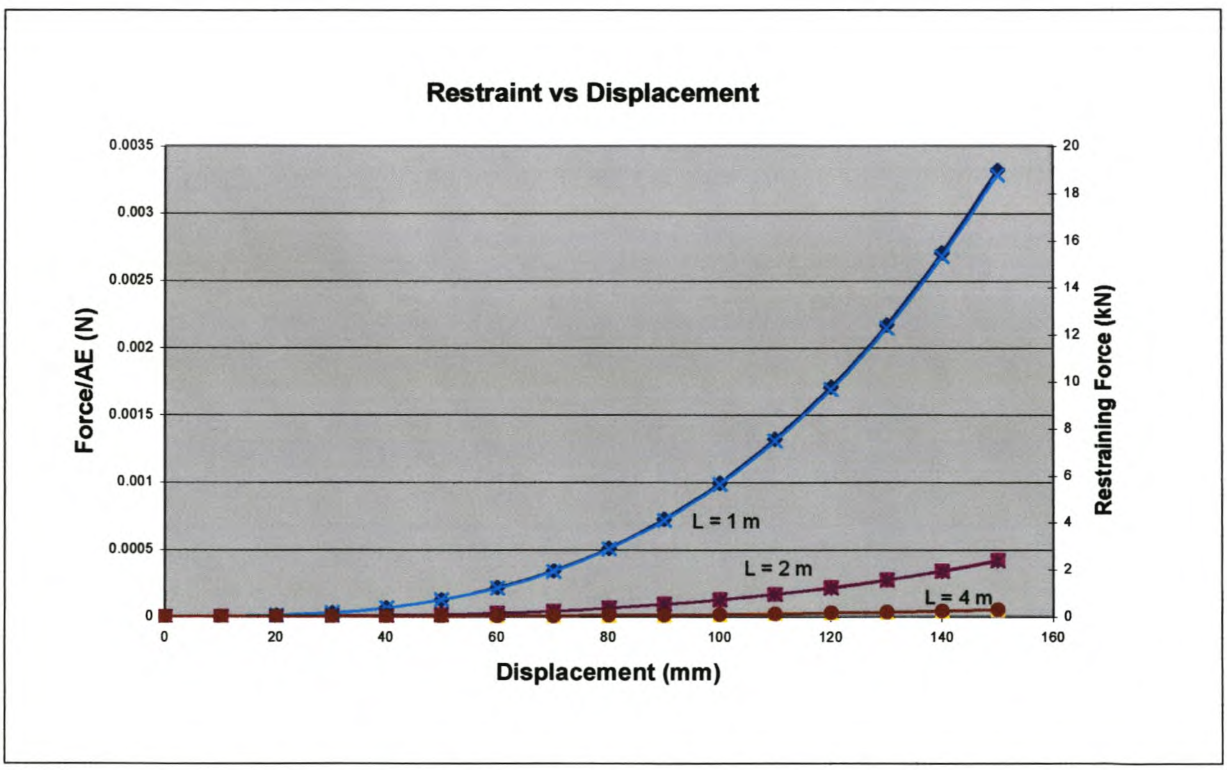


Figure 2-21 Restraint versus Displacement for Cables of various Lengths

2.3.2 Loading

Loading together with static and kinematic boundary conditions, will determine the behaviour of the column or beam being tested. This section will look at the various loading types and at the attributes of loading.

2.3.2.1 Loading Types

The basic loading types, as illustrated in Figure 2-22, include point loads, distributed loads, axial loads, coupled moments, torsional moments and displacement loading. These loads, in various combinations, will make it possible to obtain any desired force diagram required for testing.

Loads should not cause secondary loading or restraint on the beam; for example a point load should not cause a torsional moment. Loads can however be linked so that the increase in e.g. a point load will cause a proportional increase in a torsional moment.

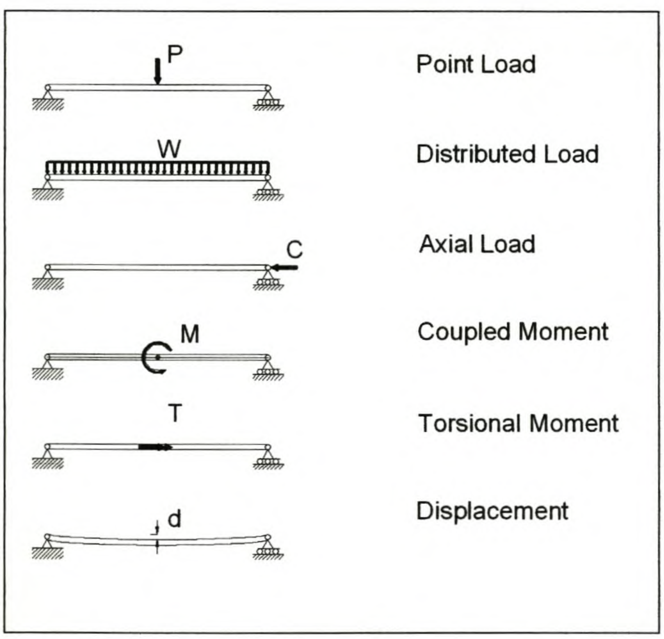


Figure 2-22 Loading on a Simply Supported Beam [1]

In the rest of this section we will take a closer look at the various basic loading types and basic loading techniques in applying these loads.

Point Load

Point loads are mostly used in the testing of beams and column due to the simple and easy way in which a point load can be set up and controlled. Equipment commonly used to create point loads, which will be discussed briefly, includes weights, hydraulic actuators and servo-hydraulic actuators.

Due to practical reasons weights are seldom used to apply large loads. Weights are however ideal for testing smaller models, display structures and test samples under a constant long term load, as weights provide discrete loading increments, are inexpensive and require neither maintenance nor calibration [5, 6]. Using weights will also not cause restraint against sway as can be seen in Figure 2-23 and will provide for true gravity loading.

Hydraulic actuators are mostly used due to the simple way in which large loads can be applied to a test sample, as they are available in various capacities. A hydraulic actuator usually consists of a piston in a casing filled with hydraulic fluid. As hydraulic fluid is pumped into the casing, the piston will extend and exert a force equivalent to the pressure of the hydraulic fluid. The capacity of hydraulic actuator refers to the stroke (maximum extension of the piston) and force of the equipment.

A common problem with hydraulic actuators, however, is restraining forces caused when structures permitted to sway are tested (as can be seen in Figure 2-23). To overcome this problem of restraining forces a gravity load simulator can be used. The simulator approximates true gravity load when it is used with a tension hydraulic actuator, as the line of action of an applied load will remain vertical even when the loaded structure sways sideways, as can be seen in Figure 2-24 [5].

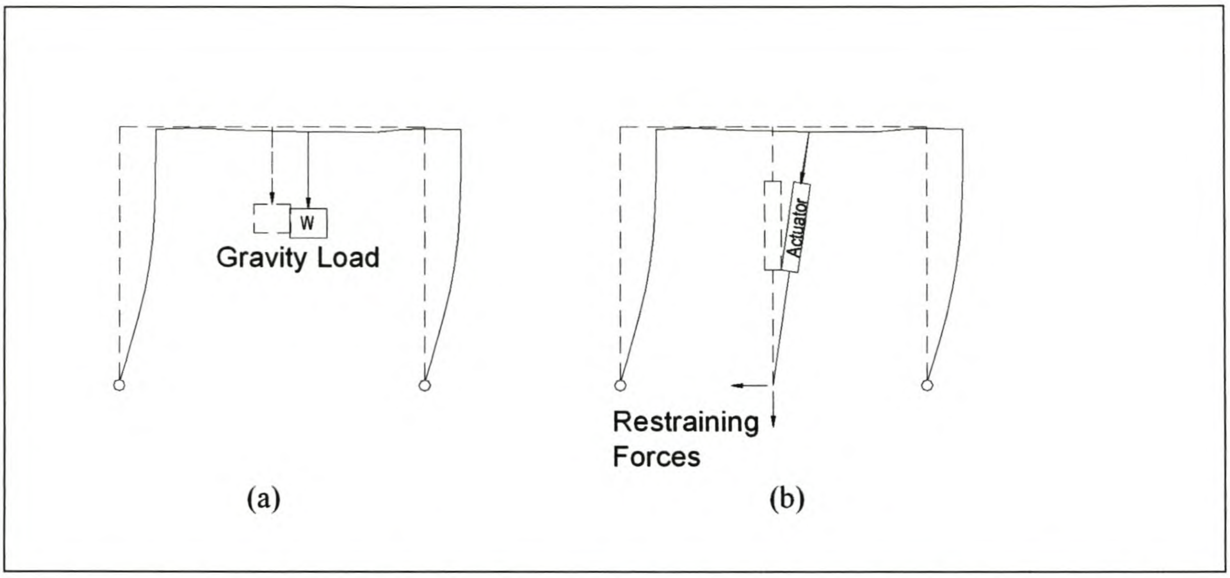


Figure 2-23 Testing Structures Permitted to Sway using (a) True Gravity Load and (b) a Hydraulic Actuators [5]

The gravity load simulator is a mechanism based on "Robert's straight-line motion". The mechanism is symmetrical and composed of three members: two inclined straight arms connected by a rigid, triangular member as illustrated in Figure 2-24. Pins are located at both ends of the inclined arms and permit plane motions with one degree of freedom. The motion of the mechanism can be determined for any given geometry (base width, top width and arm length) using graphical or analytical methods. The hydraulic actuator is connected to the gravity-load simulator at a certain point (load height) along the perpendicular bisector of the top width.

Equilibrium of the mechanism requires that the line of action of the load passes through the instantaneous centre, that is, the point of intersection of the two arms. The position of the instantaneous centre changes as the mechanism is deflected, as shown in Figure 2-24 [5].

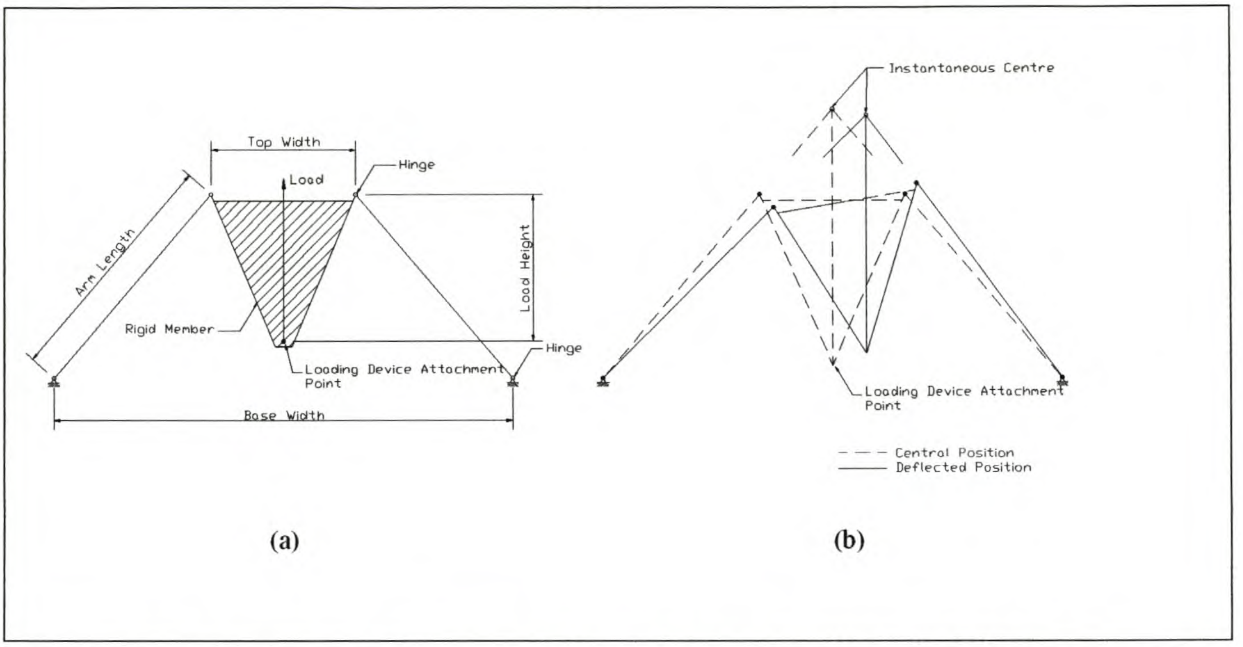


Figure 2-24 A Gravity Load Simulator showing (a) the Geometry and the(b) Deflected Shape

In order for the load to be vertical, the loading device should be attached at the point (load height) along the perpendicular bisector of the top width that is directly below the instantaneous centre. For certain choices of linkage geometry, the load height remains almost constant over a range of mechanical motion, although the instantaneous centre does change. This locus of the loading point approximates a straight line, resulting in the simulation of a gravity load. In general, the longer the arm length compared to the base width, the smaller the deviation of the calculated load height.

The difference between servo hydraulic actuators and hydraulic actuators is that the loading applied with the servo hydraulic actuator can be displacement and load controlled, also allowing for tension or a compression load. This makes actuators ideal for cyclic and impact loading. Displacement control loading and discrete loading increments can also be achieved using actuators.

Servo hydraulic actuators are however much bigger and more expensive than hydraulic actuators, limiting the use thereof.

Distributed Load

Although distributed loading is most common in practice design, it is very difficult to reproduce in a laboratory, especially for testing beams. In general however, pending on the span length, four or more point loads can be considered to be a distributed load, as illustrated in Figure 2-25 [7, 8].

Weights can be used to create an evenly distributed load, but as mentioned above, weights become impractical when large loads are required. Loading increments would also be discrete.

To create a true distributed load, a hydraulic mat or cushion can be used. The mat or cushion is placed on the beam and a stiff element placed above the cushion. When point loads are applied to the stiff element, the mat will transfer a uniform pressure to the test specimen as illustrated in Figure 2-25. This is however a time-consuming test setup and generally impractical to achieve with narrow beams.

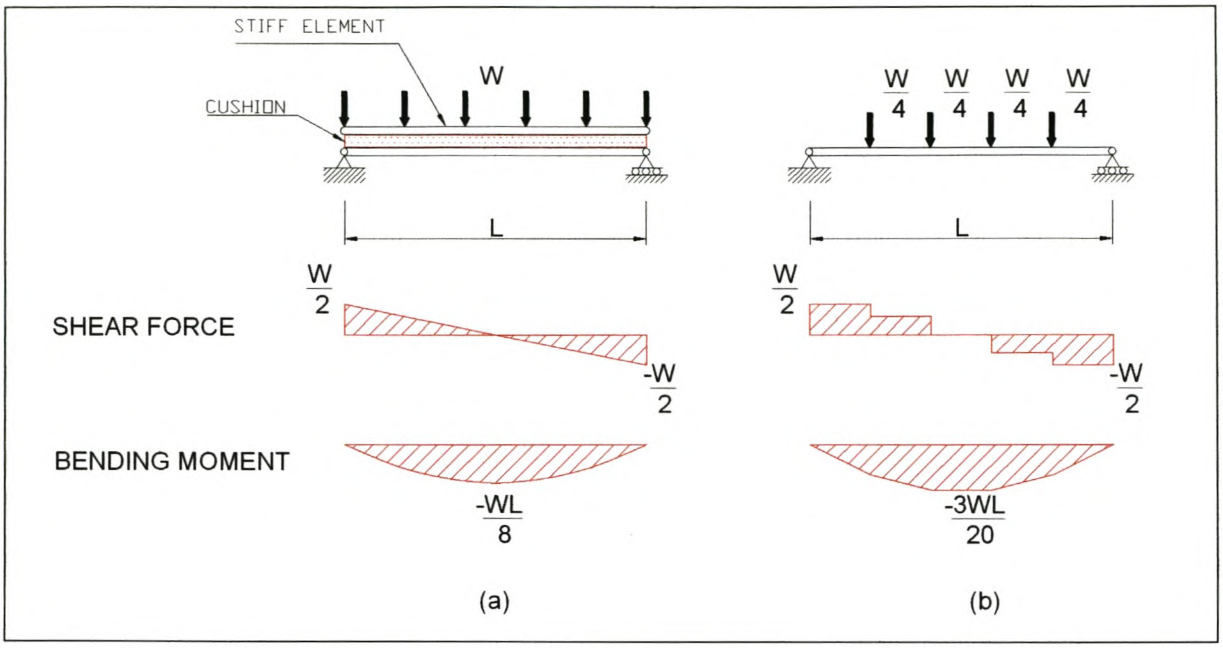


Figure 2-25 Creating a Distributed Load on a Simply Supported Beam Using (a) a Cushion and (b) Four Point Loads

<u>Axial Load</u>

Hydraulic actuators or servo hydraulic actuators are ideal to create an axial compression or tension load in a test sample. The point load needs to be applied through the centroid of the section as to prevent secondary forces.

Axial loads are mostly used to test pure compression and tension members and are seldom used in combination with other loads.

Coupled Moment

To create a coupled moment on a test sample, two equal loads (P) are applied to the test piece by means of two cantilevers (with length = h/2) fixed directly to the beam. These loads are applied in opposite directions, and are illustrated in Figure 2-26. Due to the difficulties involved with the above setup, coupled moments are seldom used in testing beams and columns.

Two point loads (P spaced b apart), applied directly to the test sample in opposite directions, can be used to approximate a coupled moment, as illustrated in Figure 2-26. As b approximates zero the shear force and bending moment diagram will approximate that of a true coupled moment. The shear force in the region between the two point loads will, however, always exceed the shear force at the supports and stiffening the test sample in this region is recommended to prevent shear failure. Alternatively, a stiff frame coupling the point loads together can be used to apply these point loads.

The approximate setup can also be used to test for shear forces as a zone with high shear forces and a moment inflection point is created.

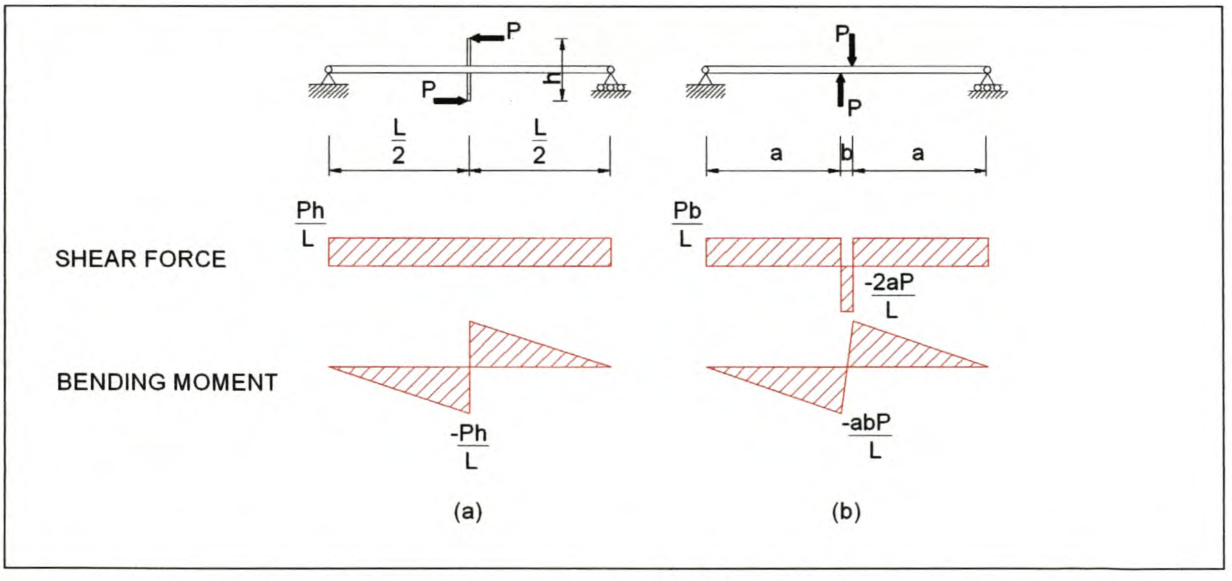


Figure 2-26 Creating a Coupled Moment by Using (a) Two Axial Loads and (b) Two Point Loads

Torsional Moment

A torsion moment can easily be applied to the test sample by using two equal point loads. The point loads are applied in opposite directions at an equal distance from the shear centre (S) of the beam to prevent secondary load effects, and are illustrated in Figure 2-27 [9, 10, 11, 12].

When testing for a combination of torsion and bending moment a single point load instead of the two point loads can be used. The point load will cause a torsional moment due to the eccentricity of the load. The value of the torsion and bending moment would be linked in relationship to the span length and the eccentricity of the point load.

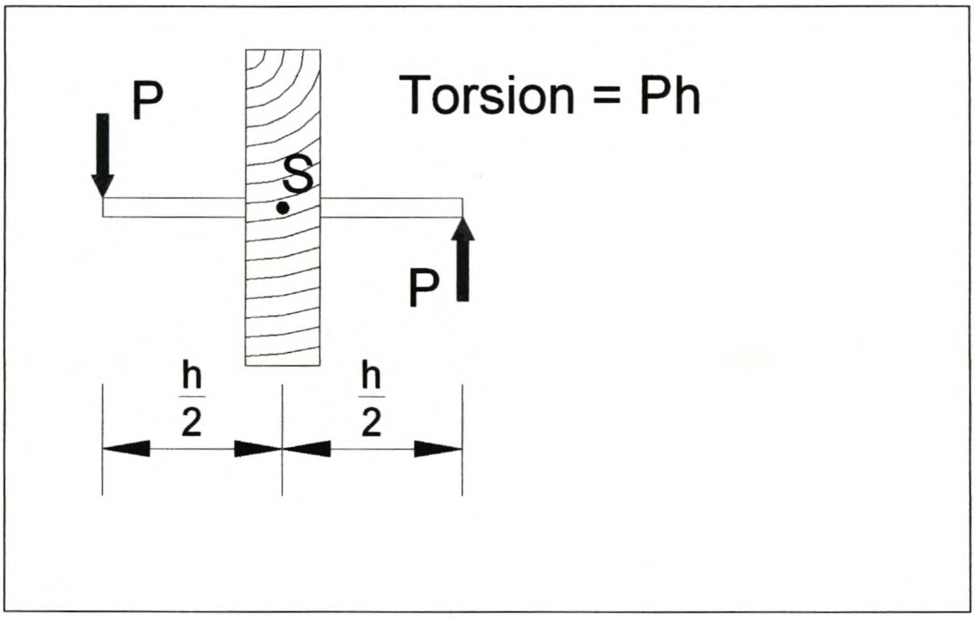


Figure 2-27 Creating a Torsion Moment using two Equal Point Loads

Displacement

Loading, regardless the type, will cause the test sample to displace. The displacement of a specific point of the test sample will depend on the loading type and can either be translation, rotation or both [13].

To apply a displacement load, any of the basic loading types can be used to create the desired displacement, but instead of using load control, displacement control of the loading is required. Hydraulic actuators are ideal to apply displacement loading, as the displacement of the actuator can be fully controlled.

2.3.2.2 Attributes of Loading

All basic loading types will display attributes of position, direction, time, magnitude, and will either be normal, stabilizing or destabilizing.

The attribute of position refers to the position of the applied point load on the test sample. If the position of the applied load is changed, the position of critical internal forces will also change. This will result in an altered behaviour and failure pattern for the specific test sample.

The magnitude or size of an applied load is directly linked to time. Pending the magnitude or size of the applied load at a specific time, the load could either be classified to be a linear or discrete static load, a cyclic load, impact, long term or random. This is illustrated in Figure 2-28.

The time is usually measured in seconds (s), although in the case of long-term loading days or months becomes more appropriate. The magnitude of the load is measured in kilonewton (kN), or in the case of displacement loading in millimetres (mm).

Loading would also be classified to be normal, stabilizing, or destabilizing. A stabilizing load would tend to prevent lateral torsional buckling, whereas a destabilizing load will increase the effects of lateral torsional buckling. A normal load will neither cause nor prevent lateral torsional buckling as the load will always work through the shear centre of the test sample, as can be seen in Figure 2-29.

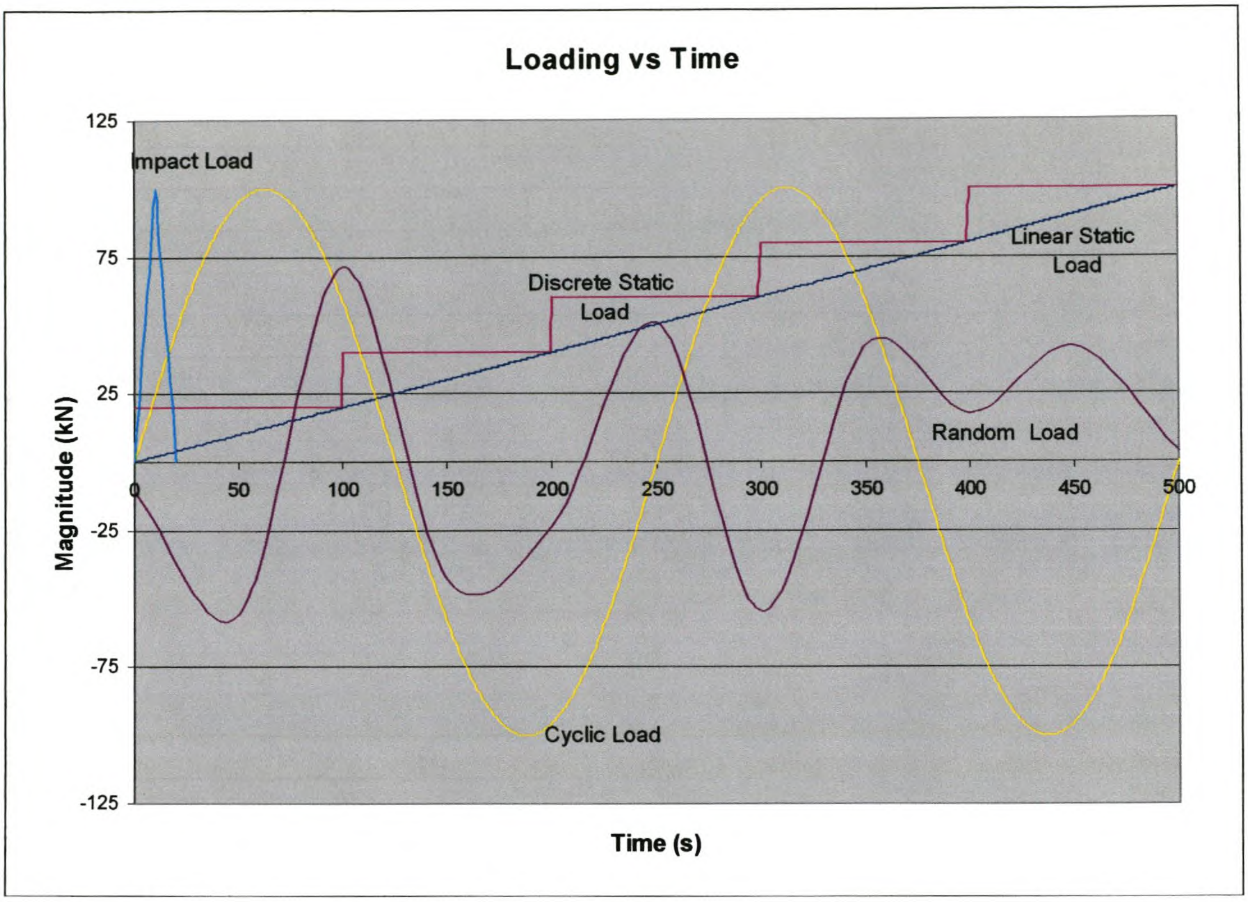


Figure 2-28 Loading versus Time Graph

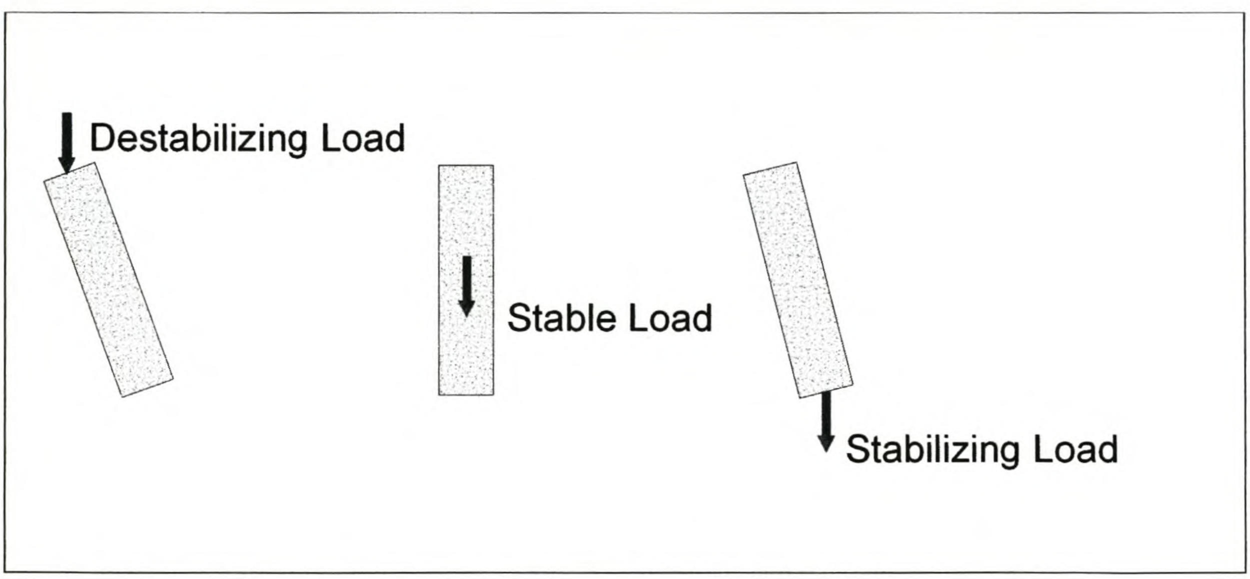


Figure 2-29 Normal, Stabilizing and Destabilizing Loads [17]

2.4 Test Data

Measurement of test data is required in order to evaluate and to draw conclusions on the behaviour of the test sample during the test. The measured data would include the measurement of the load (forces), the displacement (rotation and translation), the strain and visual observations at discrete positions on the test sample, at a distinct point in time.

Attributes of test data will include the magnitude or measured value, the position of measurement and the time of measurement.

Measurement equipment, pending on the type and age thereof, will either require the taking of manual readings or supply an analogue or digital output. Regardless of the output type, the user can convert it to digital format for later processing.

This section will take a closer look at the attributes of the measured data, as well as the measurement of test data with specific reference to the measurement equipment and the processing thereof.

2.4.1 Attributes of Test Data and Test Data Measurement

The test data and the measurement thereof, regardless of the type, will exhibit the attributes of magnitude (or the size of the measured data), the position (where the data was measured) and time (when the data was measured).

It is important for the measured values of force, displacement, strain, and visual observations to correspond to the same time value (or interval), so that the relationship between the effects can be evaluated, for example by means of a displacement/force graph.

Optimum positions and intervals for the measurement of test data will be dependent on the test setup and the attributes of the test specimen. In the following section the measurement position of the test data will be discussed for standard tests. The time between measurement and load increments should allow for the time effects that the test specimen might display.

Regardless of the type of measurement equipment, the equipment will have to be calibrated to ensure accurate readings. The equipment will also have an optimum range of measurement for which the measured data will have a minimum error. Testing outside this "optimum" value will result in errors in the test data.

2.4.2 Force Measurement

The measurement of the load or applied forces on the test specimen is required to determine the force diagram of the forces acting on the test specimen. From this, together with the measured displacement, the behaviour of the test specimen can be determined and evaluated by means of a displacement versus load graph.

Equipment used to measure force usually relates a primary effect of loading, such as deflection, pressure or strain to a load value by means of a relationship between the primary effect and the load. This relationship is usually linear in the "optimum" range of the equipment. Overloading the equipment will cause irreparable damage to the accuracy thereof.

Measure equipment includes load rings, pressure gauges and load cells. The load ring would be calibrated to relate the deflection of the ring to a force. Similarly pressure gauges are calibrated to relate the pressure of a hydraulic fluid to a force. Load cells, the most commonly used method of load measurement, consist of a set of calibrated strain gauges in a casing. The differential voltage over the strain gauges is related to a differential strain from which the load can be calculated.

2.4.3 Displacement Measurement

The displacement is measured together with the force in order to define the behaviour of the test specimen. As mentioned above, this relationship is usually determined by means of a displacement versus load graph.

The most frequently used equipment to measurement displacement would include dial gauges and linear voltage displacement transducers (LVDT).

A dial gauge consists of a pin connected to a dial. As the pin is pressed in or pulled out, the corresponding displacement of the pin is mechanically displayed on the dial. Although dial gauges require the taking of manual readings, it is still used especially with display experiments, as it is easy to install, inexpensive and requires no calibration.

The LVDT consists of a pin similar to that of dial gauges in a casing. As the pin is pressed in or pulled out, a voltage difference is measured over the LVDT. In the "optimum" range of the equipment this difference in voltage can be measured electronically and the relative displacement can be calculated from the linear relationship between the voltage difference and the displacement. Working outside of this "optimum" range will cause inaccurate displacement readings.

To measure rotation, the linear displacement of a lever arm of known length is measured. The rotation about the centre of the lever arm can then be calculated from basic geometric principles.

2.4.4 Strain Measurement

Strain is an indication of deformation and can be defined as the change in length of an element divided by the original length (units being mm/mm). If the material properties of the test specimen are known, the stress can be obtained from the stress/strain relationship. With the stress known and the sectional area known (a geometric property) the force in the element can be calculated.

Equipment used to measure strain includes strain gauges, and strain meters. A strain gauge can be defined as an electronic resistor that is glued to the test piece that will allow it to deform corresponding to the deformation of the test piece. The deformation (lengthening and shortening) of the strain gauge will result in a change in resistance, resulting in a change in the voltage. This voltage/resistance change can be measured and the corresponding strain can be calculated from basic electronic principals.

As strain gauges are glued to the test piece with an epoxy in order to ensure the same deformation as the test piece, it can only be used for testing a specific test specimen. Strain gauges are available in various sizes (even to measure strain over a 5mm length) making it ideal for testing local strain. It is also made to suit various material types; such as steel, concrete and aluminium, by having the temperature coefficient of the gauge match that of the material. This allows one to ignore temperature variations that might occur during testing.

Strain meters are divided in two types, namely those using strain gauges and those using linear displacement measurement equipment such as LVDT's and dial gauges. The first type consists of a strain gauge in a casing. The casing is glued to the test specimen allowing for the measurement of strain and can be removed after testing.

The second type consists of a LVDT or a dial gauge that is used to measure the deflection over a known length. From this deflection the strain can be calculated.

Strain meters are not material specific and will only measure the strain over a bigger base length. One big advantage of strain meters over than of strain gauges is that they can be used on more than one test specimen.

2.4.5 Visual Observations

Visual observations form an important part of the test data, although the method of failure and a photo of the test sample before and after failure, and in the case of concrete beams, the forming and sizes of cracks, are usually the only recorded observations.

Although seldom recorded, visual observations verify the authenticity of the recorded test data, such as the deflections. Any deviations of the behaviour of the test sample or test setup needs to be observed and recorded. The observer might require a test to be stopped, ignored or rerun due to a variation or error in the test setup or test sample following the visual observations during testing.

Photos form an important part of visual observations provided the test number and the time of the photo is recorded. Photographic, digital and video recording cameras, together with other written notes, can be used by the observer in order to record all visual observations.

2.4.6 Processing of Test Data

Before conclusions can be drawn, the collected test data must be processed. This will require the calibrating, and plotting of collected test data so that the relationship between force, displacement and strain can be determined. From these relationships the behaviour of the test specimen can be evaluated.

Computers and spreadsheet programmes are mainly used in this process of calibrating and plotting, such as displacement versus load graphs, from which conclusions can be drawn. This will be illustrated in chapter 6 by means of a practical example.

2.5 Frequently Used and Standard Test Setups

Standard tests are specified and frequently used to ensure comparable test results. This allows for the exchange of test data between testing facilities and the enhancing of research capabilities. Frequently used and standard tests will ensure a desirable force diagram over the test sample, allowing for cost effective, practical testing.

This section will take a closer look at frequently used and standard test setups with specific reference to the uses, advantages, limitations, data collecting and variations of each setup. These setups include a simply supported beam with a point load at mid span, a simply supported beam with point loads at third span and a cantilever beam with a point load at the free end.

The standard test setups only give the position of the (lateral and end) equilibrium supports. With these setups the lateral stability supporting positions and type of restraint can be varied along the length of the test sample to create the desired setup. As previously discussed the (supports and lateral) supports will affect the effective length of the beam, influencing the test results. In most tests however the test element are pinned against lateral and torsional movement at the supports.

The application of a loading to either the tension or compression face of the beam could also influence the test result as this will either be stabilizing or destabilizing and need to be considered in the test setup.

2.5.1 Simply Supported Beam with a Point Load at Mid Span

Testing a simply supported beam with a point load at mid span enables one to test for a combination of shear and bending forces. It can also be used to test the local behaviour of a test sample, such as web crippling and yielding, under a point load. The test setup and the force diagram for a simply supported beam with a point load at mid span are illustrated in Figure 2-30.

The test sample is set up as a simply supported beam and a point load (either deflection or load controlled) is applied at mid span. The value of the applied point load and the deflection at mid span needs to be measured so that the deflection/force diagram can be plotted. In addition to measuring the applied force and deflection, strain gauges can also be used at mid span to measure the stress in the beam.

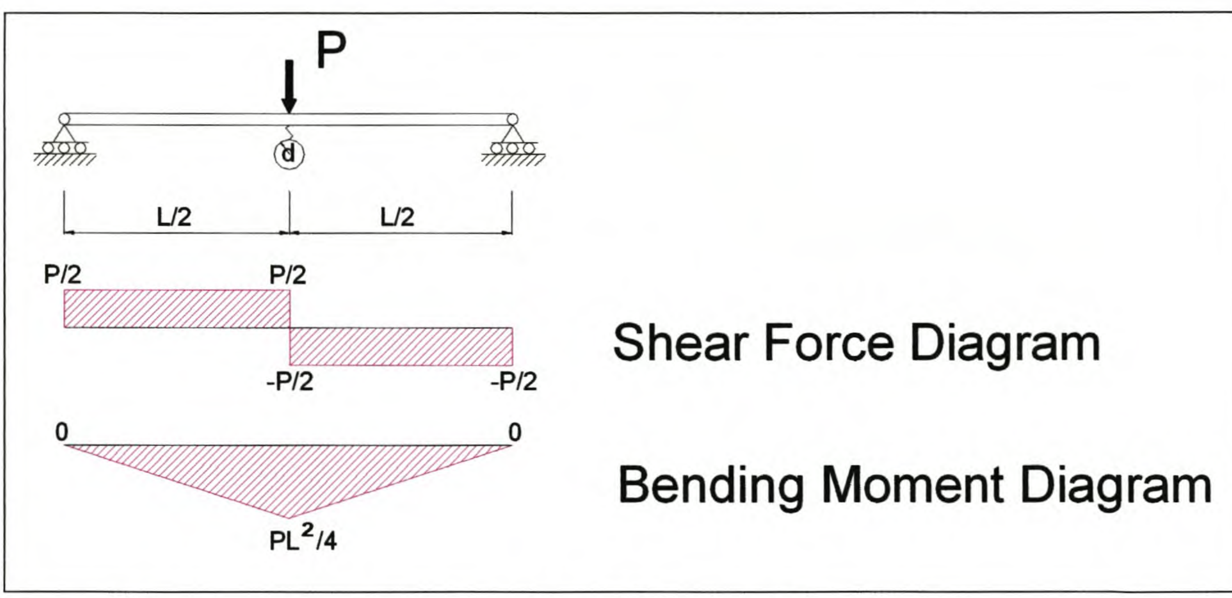


Figure 2-30 Simply Supported Beam with a Point Load at Mid Span

The test setup is reasonably simple to achieve as only one point load is applied (and measured) and the deflection of only a singular point measured, reducing the amount of resources required for testing.

A typical variation to the test setup will enable the user to test for shear (with a relative small moment) by having the point load moved closer to the support. The deflection of the beam can then be measured at the loading point or at mid span.

2.5.2 Simply Supported Beam with Point Loads at Third Points

A simply supported beam with point loads at third points will enable one to test for constant moment (without shear forces) over the central third of the test sample. The test setup and the force diagram are illustrated in Figure 2-31.

The test sample is set up as a simply supported beam and point loads (either deflection or load controlled) are applied at third points. The value of the applied point loads and the deflection at mid span need to be measured so that the defection/force diagram can be plotted.

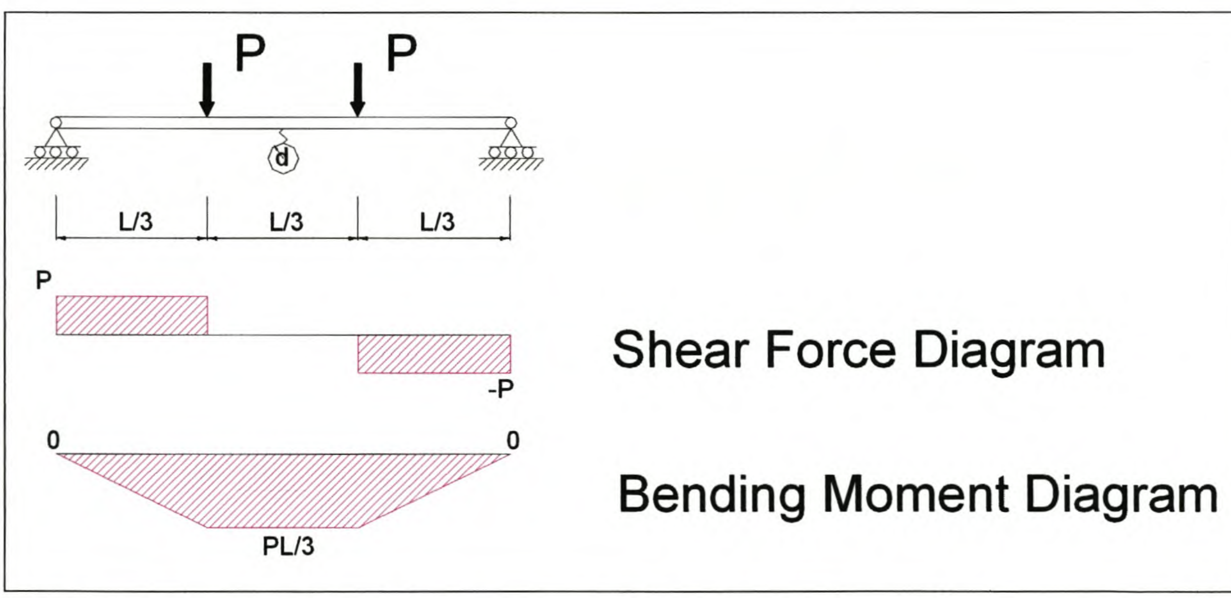


Figure 2-31 Simply Supported Beam with Points Load at Third Points

The force diagram makes this test setup ideal for testing a beam under pure bending stress and in addition to measuring the applied force and deflection, strain gauges can also be used at mid span to measure the stress in the beam.

The test setup is reasonably simple to achieve, but will require the measurement and control of two point loads in addition to the deflection. Controlling these point loads to ensure the same load at all times will require special loading equipment or manual adjustments during testing.

Although the tests might be varied, the principle of the test remains the same, and a constant bending stress, without shear stresses, is achieved over a section of the test sample. Typical test variations include testing at quarter points and measuring the deflection at the loading positions.

2.5.3 Cantilever Beam with a Point Load at the Free End

Cantilever beams with a point load at the free end will allow for the testing of rigged and semi-rigged connections. The connection at the fixed end will be submitted to a combination of shear and bending, making it ideal for testing moment-rotation relationship of connections. This shear/moment relationship is dependant on the length of the beam, which in this case is defined as the distance from the fixed end to the position of the load. The test setup and the force diagram for a cantilever beam with a point load at the free end are illustrated in Figure 2-32.

The test sample is set up as a cantilever beam and a point load (either deflection or load controlled) is applied at the free end. (Note that if the free end of the beam is not restrained against lateral or tosional movement, SABS 162:1-1993 [2] gives the effective length of the beam as 1.4L for loading to the tension flange. If the load is applied to the top flange the difference in effective length can be as much as three times that for bottom flange loading under the same restraints at the fixed end.)

The value of the applied point load and the deflection at various positions along the span of the beam are measured. For moment/rotation relationships measurement of deflection should be close to the fixed end as it assumed the beam flexure will be smallest closest to the support. As more than one deflection is measured along the length of the beam, the beam flexure can be calculated and any moment/rotation readings corrected. The rotation of the support (or connection plate) also needs to be measured. A diagonal measurement will also be required if the support is allowed to deform or rotate in the experiment [21]. Strain gauges can also be used at the fixed end to determine the stresses at the connection point.

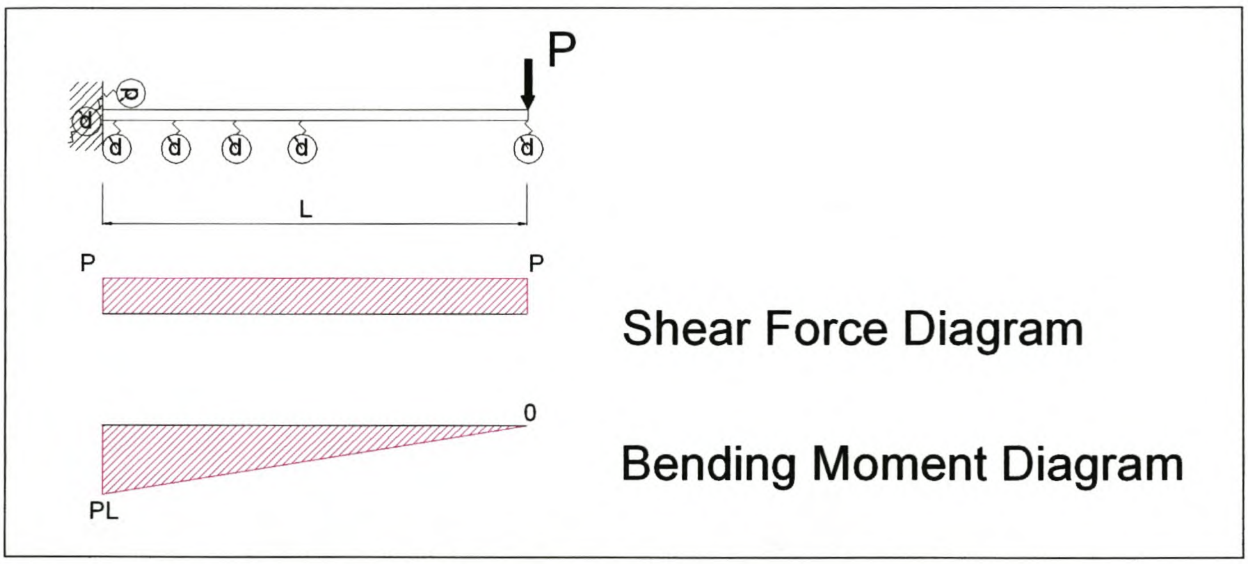


Figure 2-32 Cantilever Beam with a Point Load at the Free End

3 REQUIREMENTS AND THE DESIGN PHILOSOPHY OF THE MULTI-PURPOSE BEAM/COLUMN TESTING APPARATUS

3.1 Introduction

This section stipulates the requirements the MTA must adhere to in order to fulfil its function as a true multi-purpose testing apparatus. The requirements will be discussed under the following headings:

- General Requirement
- Test Setup Requirements
- Loading Requirements
- Static and Kinematic Boundary Requirements
- Design Philosophy

3.2 General Requirements

Under general requirements practical, visual and the use of existing testing frames and loading and measurement equipment will be discussed.

3.2.1 Practical Requirements

Although the testing apparatus will have a dedicated area on the main test floor it needs to be removable from the test floor. Once removed it needs to take up the minimum storage space.

The test setup needs to be changed in the minimum time with the minimum effort. The required change not only include changing specimens, but also changes to test various beam and column specimens of different sizes under different loading and static and kinematic boundary arrangements.

The testing apparatus needs to be low in maintenance in order to keep the long-term costs down to a minimum. Low maintenance includes aspects such as the cleaning, painting and upgrading of the testing apparatus. Making changes to the test setup or upgrading the testing apparatus will have to require bolting and not welding, as welding will require local rust protection afterwards.

As safety in any workplace or laboratory is essential, the apparatus needs to comply with all regulations of the Law on Career Safety (Law 85 of 1993). The apparatus should be designed to ensure the safety of the researcher and other test onlookers. Tripping hazards should also be avoided.

3.2.2 Visual Requirements

Visually it is required from the test setup to be aesthetically pleasing, as the beam/column test specimen will be on display for visitors.

For report requirements on any test specimen the test specimen and the test layout are usually photographed. Not only does a well-arranged test setup promote a professional impression, but also a clean, well-kept testing environment.

The ease of cleaning the testing apparatus is a requirement in order to maintain a visually well kept testing environment. Brackets and welded angles promoting dust collection on the test apparatus should also be kept to a minimum.

Welding on the testing apparatus will damage the paint and leave the structure to rust locally if the welding is not rust protected. In order to prevent this, test alterations should be made without welding onto the testing apparatus.

3.2.3 Use of Existing Equipment

The Structure Laboratory, University of Stellenbosch, is equipped with a limit number of loading frames that are bolted at the discrete fixing points. The use of the multi-purpose beam/column testing apparatus should not prevent the use of these frames and should therefore not make use of the whole test floor.

The multi-purpose beam/column testing apparatus will also have to make provision for two gravity load simulators (each with a capacity of 200 kN vertical loading) and three servo-hydraulic actuators (2x 62.5 kN and 1x600 kN).

Existing measurement equipment, including load cells and LVDTs, can easily be used with any testing apparatus as they are relatively small and can easily be setup within the limits of a testing apparatus.

The actuators and gravity simulators will most likely have to form the basis from which the multi-purpose beam/column testing apparatus has to be designed, as replacing these will be too costly. The apparatus has to be designed so that the use of other (future) loading equipment can easily be accommodated.

3.3 Test Setup Requirements

Requirements regarding the test setup will include beam setup requirements, minimum and maximum size requirements and maximum loading requirements.

3.3.1 Beam Setup Requirements

The beam testing apparatus should make provision to test cantilever beams, simply supported beams, propped cantilevers, beams with overhung ends, fixed end beams and continuous beams as defined in the previous section.

Due to financial restraints, and current only two supports would be built. The support should however be designed that a third or fourth support can be added should the need arise in future.

An axis system should be defined on the testing apparatus so that the beam setup and loading can be referenced.

3.3.2 Minimum and Maximum Beam Size Limitations

The testing apparatus will have to cater for beams of various sizes. Due to practicality and other restrictions, such as the size of the test floor, the test specimen size will have to be restricted to the sizes given in Table 3-1.

Size	**Single Span (m)**	**Multi-span (m)**	**Height (m)**	**Width (m)**
Minimum	2	2x2	-	-
Maximum	10	2x5	1.5	2.7

Table 3-1: Maximum and Minimum Sizes for Test Specimen.

3.3.3 Maximum Loading Capacity

The maximum load that can be applied to a test specimen will be limited due to the available loading equipment and the capacity of the floor. These requirements are given in Table 3-2.

Test Floor Capacity	**Maximum Load (kN)**
Vertical	400 kN at 920 c/c for 4 points
Horizontal	200 kN at 920 c/c for 4 points
Loading Equipment Capacity	**Maximum Load (kN)**
Vertical: 500 kN Servo Hydraulic Actuator Gravity Load Simulator	 600 kN (Static) 500 kN (Dynamic) 200 kN
Horizontal: (Lateral and Axial) 500 kN Hydraulic Actuator (2 off) 200 kN Hydraulic Actuator (2 off)	 500 kN 200 kN

Table 3-2: Maximum Loading Capacity

3.4 Loading Requirements

The test setup must cater for various loading requirements. The loading will be discussed under two separate headings:

- Loading Type
- Forces on the Test Specimen.

3.4.1 Loading Type

As discussed in the previous chapter, the type of loading refers to loads and position of these loads on the test specimen. The testing apparatus must make provision for both displacement and force controlled loading. The loading, being a function of time, will either be static, dynamic or a combination of static and dynamic loads.

The apparatus will have to make provision for a combination of point loads (and distributed loads), applied in a normal (stabilising) or a destabilising arrangement. These loads are to be applied in a vertical, horizontal, axial direction or a combination of these.

3.4.2 Forces on the Test Specimen

The position and the type of loads will result in forces on the test specimen. When testing a simply supported beam a single point load would cause a combination of bending and shear forces in the beam. When a pure moment is required two point loads can be used to ensure a combination as discussed in the previous section. When only shear is required the point load needs to be close to the support to ensure the shear force is dominant.

Although current research require the testing of beams under pure torsion, shear, bending or a combination of shear and bending the loading requirements of future research should not be overlooked.

The testing apparatus should therefore make provision so that the test specimen and loading arrangement can be changed to result in the desired forces on the test specimen. These forces (a total of 128 combinations) include the following:

- Pure Bending (vertical and lateral)
- Pure Shear (vertical and lateral)
- Pure Torsion
- Pure Axial Force
- Combination: Bending (vertical and horizontal) and Shear (vertical and lateral)
- Combination: Bending (vertical and lateral) and Torsion
- Combination: Bending (vertical and lateral) and Axial
- Combination: Shear (vertical and lateral) and Torsion
- Combination: Shear (vertical and lateral) and Axial
- Combination: Torsion and Axial
- Combination: Bending (vertical and lateral), Shear (vertical and lateral) and Torsion
- Combination: Bending (vertical and lateral), Shear (vertical and lateral) and Axial

- Combination: Bending (vertical and lateral), Torsion and Axial
- Combination: Shear (vertical and lateral), Torsion and Axial
- Combination: Bending (vertical and lateral), Shear (vertical and lateral), Torsion and Axial

3.5 Static and Kinematic Boundary Requirements

By changing the boundary conditions, the beam setup will change and this will result in a different failure load or even mode for the same test specimen as the effective length of the specimen will changes as discussed in the previous chapter. It is therefore important for these boundary conditions to be as flexible as possible. These requirements are discussed for the end supports and for the lateral supports.

3.5.1 End Supports

The end supports need to be variable so that various beam sizes can be tested. The minimum and maximum beam sizes were discussed in section 3.3.2.

Due to the variability of the length of the test specimen, the distance between the supports is to be variable. It is also required that the supports be adjustable in height and width in order to test beams of various heights and widths, using various loading arrangements.

The end supports should make provision for various boundary conditions as discussed in the previous chapter. This will include having the beam end pinned or fixed. Provision for axial and lateral restraints and loading is also required. This would require that the supports to be designed to be "fitted" with the required boundary condition and not to have a set (unchangeable) boundary condition.

The end supports will have to resist the reaction forces due to the loading on a test specimen. The maximum possible load applied to a test specimen is given in Table 3-2. Deflections of the supports under such loading will have to be small compared to the deflections of the test specimen so that the effect thereof can be ignored. Loading also needs to be applied at the end supports.

3.5.2 Lateral Supports

When testing an element such as a beam, lateral support (either stability or equilibrium) will be required. The lateral supports will have to provide support at various positions and at various heights along the beam length. Lateral supports will also be required at the end supports.

The lateral supports must also make provision for the measurement and the application of lateral forces. The lateral support should not cause restraints where restraints are not required.

One should therefore be able to vary the lateral supporting mechanism used to suite the requirements of the specific test (different types of systems was described in the previous chapter).

3.6 Design Philosophy behind the development of the MTA

With the development of the MTA various test setups and systems were evaluated with reference to the requirements as discussed above and in chapter 2 (The list of research articles, discussing a verity of structural tests, used for this purpose appears at the back of the references under the heading: List of Background Articles)

.

Most systems make either provision for testing beams (using lateral loads) or columns (using axial loads) and are restricted in specimen size, and loading capacity (either position, direction or size of the load). The static and kinematic boundary conditions can seldom be varied and make no provision for the use of different lateral supporting mechanisms. To vary the lateral supporting mechanism from the "standard" test of the machine requires either a new testing apparatus or major alterations to the testing apparatus.

In the development of the MTA flexibility played a big part to ensure the use of various static and kinematic boundary conditions, loading arrangements and specimen sizes. Varies concept of testing systems were evaluated, refined, re-evaluated, till a true multi purpose testing apparatus was developed. In the following chapter this system will be discussed, looking in detail at each component.

4 DESCRIPTION OF THE MULTI-PURPOSE BEAM TESTING APPARATUS

4.1 Introduction

The Multi-purpose Beam/Column Testing Apparatus (MTA) was developed to comply with the requirements as set out in the previous chapter. An illustration of the apparatus can be seen in Figure 4-1.

The various components of the MTA was designed in accordance with SABS 162: 1- 1993 The Structural use of Steel Part 1: Limit-States Design of Hot-Rolled Steelwork [2] and Structural Steelwork Connections (Limit States Design) [29]. The Southern African Structural Steelwork Detailing Manual [30] was used to assist in connection details. The detail design can be found in appendix C and a summary of a capacity can be found in appendix D. The detail and workshop drawings of each component of the MTA can be found in Appendix A.

As undergraduate students would also use the MTA, the above approach was chosen to allow the students to verify special test requirements. It would however be recommended to measure all static and kinematic imperfections (deflections/rotations) of the apparatus if required and not just to rely on the calculated values.

With this apparatus any size of beam (complying to the requirements, with prescribed boundary conditions, can be tested under various loads and loading conditions. It is designed for testing beams under Uni- or bi-axial bending, shear, torsion, axial loading or any combination of the above-mentioned forces.

The system consists of 4 main components, namely:

- The tracks, forming the basis of the set-up
- The loading bridges, for applying the vertical loads
- The end supports, supplying a vertical reaction at the beam-ends

- The lateral supporting frame providing lateral support along the test specimen, making lateral loading possible.

In this chapter a co-ordinate system for the MTA is defined and the various components of the test setup are described. The versatility of the MTA will be demonstrated by means of illustrations indicating various test setups and loading arrangements.

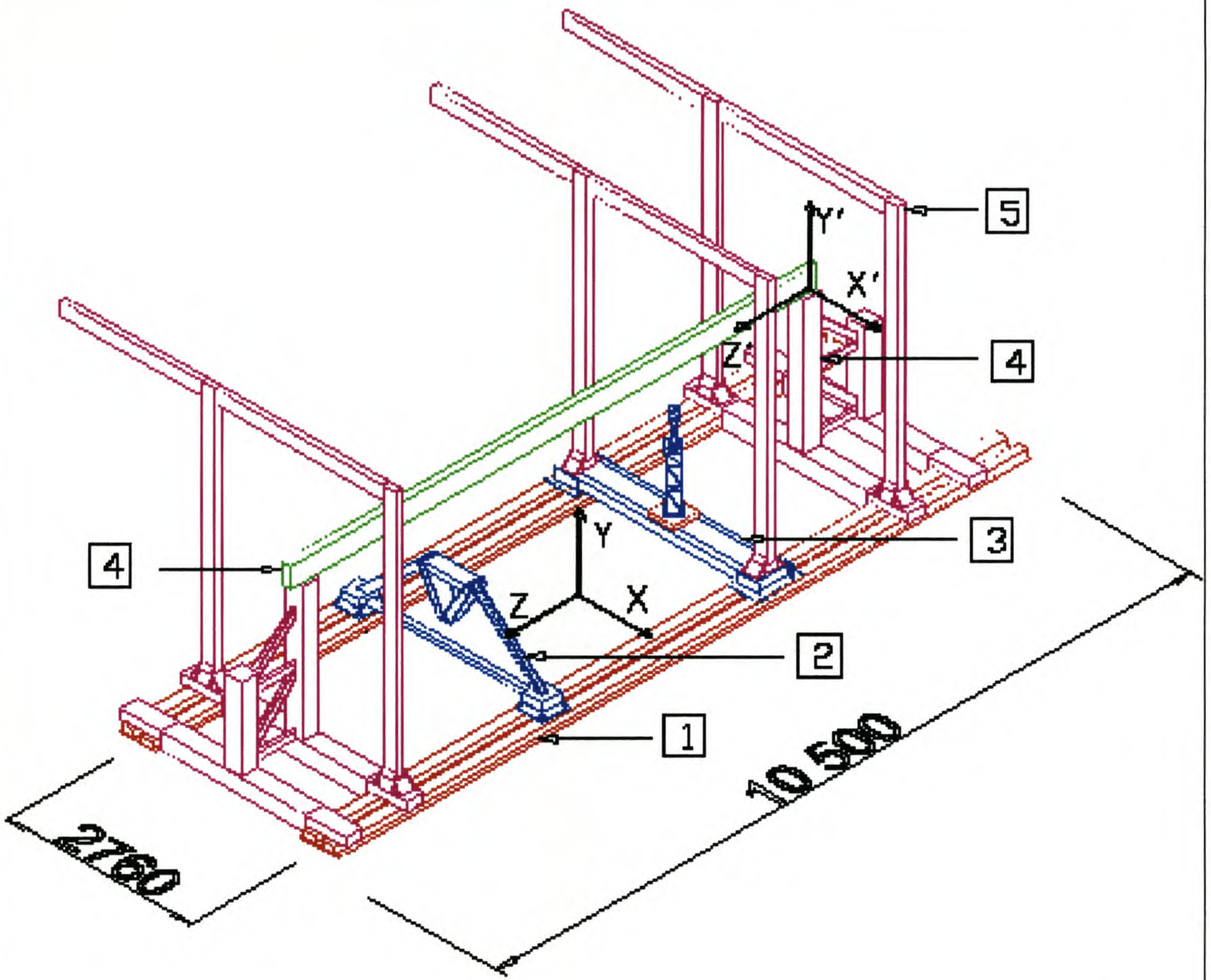
4.2 Co-ordinate System for Testing Beams

The co-ordinate system of the MTA is defined as indicated in Figure 4-1. The (0; 0; 0) co-ordinate is situated in the centre between the tracks at the top of concrete (TOC) level of the test floor. This implies that the Y-axis would be vertically perpendicular to the tracks, with the positive direction defined in the upward direction. The direction of the X-axis would be horizontally perpendicular to the tracks (parallel to the test floor) and the Z-axis is parallel to the direction of the tracks (and the test floor). Due to the double symmetry of the MTA about the X- and Y- axis, the positive directions of the X- and Z-axis are defined to the preference of the user as long as the right hand rule is applied.

With the beam setup as in Figure 4-1, the direction of the X and Y-axis of the MTA corresponds with the direction of the x and y-axis of the beam. The Z-axis will be in the direction of the beam length.

By using a co-ordinate system, the setup for a specific test can be recorded in simple co-ordinates. Alternatively the X'- Y'- Z'-axis can be used. The X'- Y'- Z'-axis are defined in the same direction as the X- Y- Z-directions respectively, but the (0; 0; 0) co-ordinate would be under one of the supports, as can be seen in Figure 4-1.

To create a bending moment about the x-axis of the beam, a force in the Y-direction is required. If the transverse (X- or Y- direction) loading is not applied through the shear centre of the section of the beam, it will result in torsion in the beam.



1. Track

(2 number of)

2. Gravity Load Simulator

(2 number of)

3. Actuator Bridge

(2 number of 62.5 kN,

1 number of 600 kN)

4. End Support

(2 number of)

5. Lateral Support Frame

(5 number of)

6. Beam

Figure 4-1 General Layout of the MTA

4.3 The Tracks

The MTA consists of two tracks, spaced 2760 mm apart, as illustrated in Figure 4-1. The tracks are bolted to the main test floor along its length (at 920 mm centre to centre) using dywidag bars. The tracks are made up of 4 angles welded to a base plate in order to create a composite section with a double set of grooves, as illustrated in Figure 4-2.

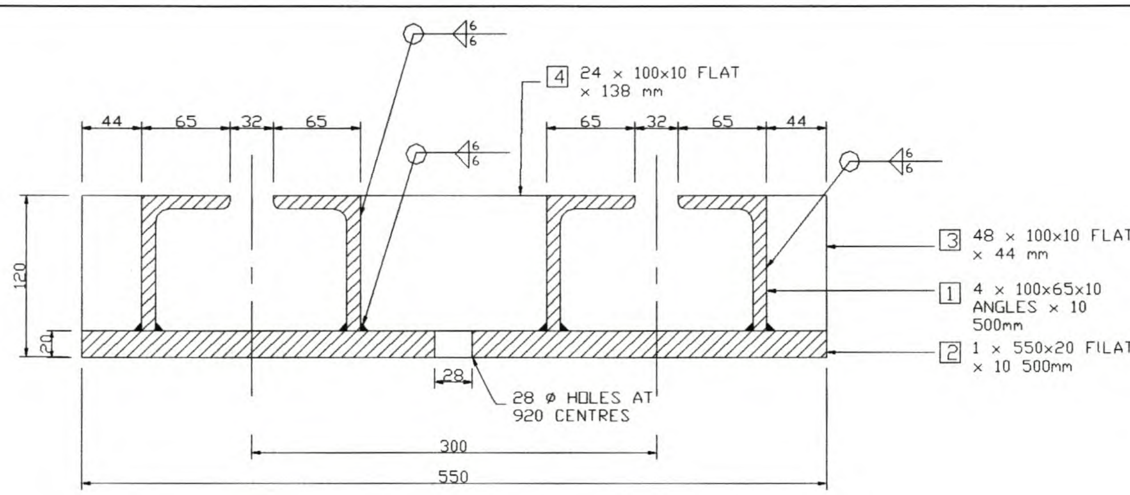


Figure 4-2 Typical Cross section through a Track

The tracks form the basis of the MTA with the loading bridges, the support bridges and the lateral supporting frames bolted to the tracks in order to span from one track to the other, as can be seen in Figure 4-1. This makes it possible to move the loading bridges, the end supports and the lateral supporting frames along the tracks (over the fixing points of the test floor), to where required.

The tracks are designed to transfer the vertical and horizontal forces applied to the test specimen into the test floor. Due to the nature of the composite section, applying torsion to the tracks is not recommended (Maximum torsional resistance = 12.2 kNm). To prevent torsion, a hinge mechanism is designed as indicated in Figure 4-6. The hinge is described in more detail in section 4.4.2

The length of the main track is limited to 10.5 m so that the track can fit across the width of the test floor. This will enable the testing of beams of lengths of up to 10.25 m. For testing longer beams, the tracks can be rotated 90° so that it runs along the length of the test floor and tracks used for the end supports. This will be illustrated in section 4.7.2.

[For the design of the tracks refer to Appendix C.2.1 and for detail drawings to drawings 01-3D-01, 01-01/1 and 01-01/2 in Appendix A]

4.4 The Loading Bridges

Vertical loading (loading in the Y-direction) is applied onto the test specimen via the loading bridges. As mentioned in the previous section, the loading bridges span between and are moved along tracks to the desired location.

Two types of loading bridges are available for use, namely the gravity load simulator, and the actuator loading bridge.

4.4.1 The Gravity Load Simulator

Gravity load simulators, as discussed in chapter 2, will enable an applied load to remain vertical even when the structure sways sideways. Two gravity load simulators, as illustrated in Figure 4-1 and Figure 4-3, were part of the existing laboratory testing equipment that had to be reused.

To achieve this, two connectors were designed to connect the simulator to the tracks. This enables the application of a true gravity load centrally between the tracks. The connectors, however, do not make provision for the connection of the lateral supporting frames, as no lateral support would be required when a structure is permitted to sway.

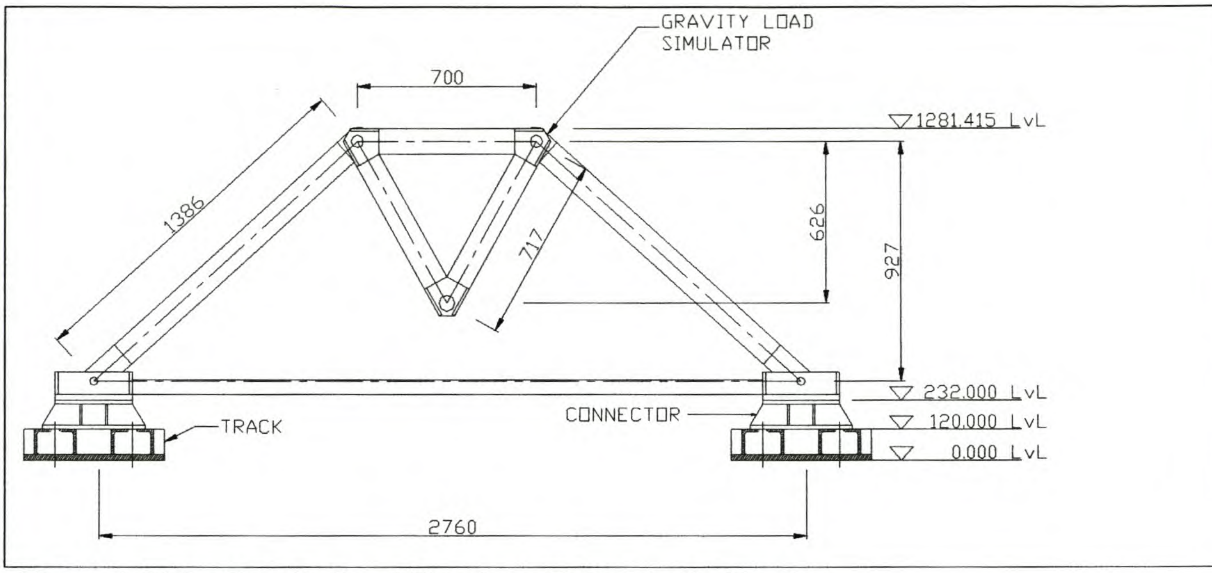


Figure 4-3 The Gravity Load Simulator Bolted to the Tracks

As can be seen from the theoretical behaviour of the gravity load simulator (illustrated in Figure 4-4) the loading height varies less that 1 mm over a side sway of 250 mm, and can be ignored for practical purposes. Restraining forces caused due to the slope of the load will also be insignificant as the slope of the load is approximately vertical.

[For the design of the gravity load simulator refer to Appendix C.2.2.1 and for details drawings to drawings 03-3D-04, 01-01/1 and 03-03/2 in Appendix A]

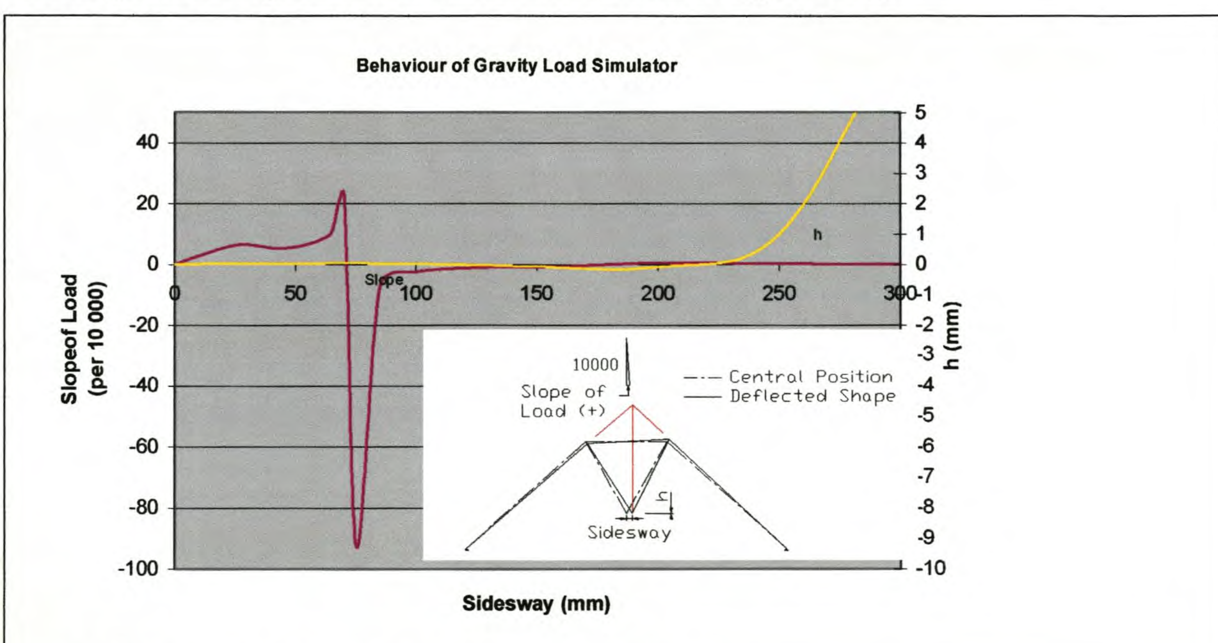


Figure 4-4 Behaviour of the Gravity Load Simulator

4.4.2 The Hydraulic Actuator Bridges

The hydraulic actuator bridges make provision for the use of the existing servo hydraulic actuators in the application of a vertical load, as can be seen in Figure 4-1.

Two types of bridges were designed for the servo hydraulic actuators. One bridge was designed to carry the 500 kN servo hydraulic actuator and the other designed for the 50 kN servo-hydraulic actuator. Other loading equipment, such as the 200kN hydraulic actuator, can also be used with the bridges by simply bolting a loading frame to the bridge, as will be illustrated later.

The composite section of the bridges is formed out of plates welded together in order to form two grooves similar to that of the tracks. The servo hydraulic actuator, or other loading equipment, is then bolted to the bridge and can be moved along the grooves of the bridge to any position. This allows for the application of a load between the tracks. The cross section of the 500 kN load bridge is illustrated in Figure 4-5.

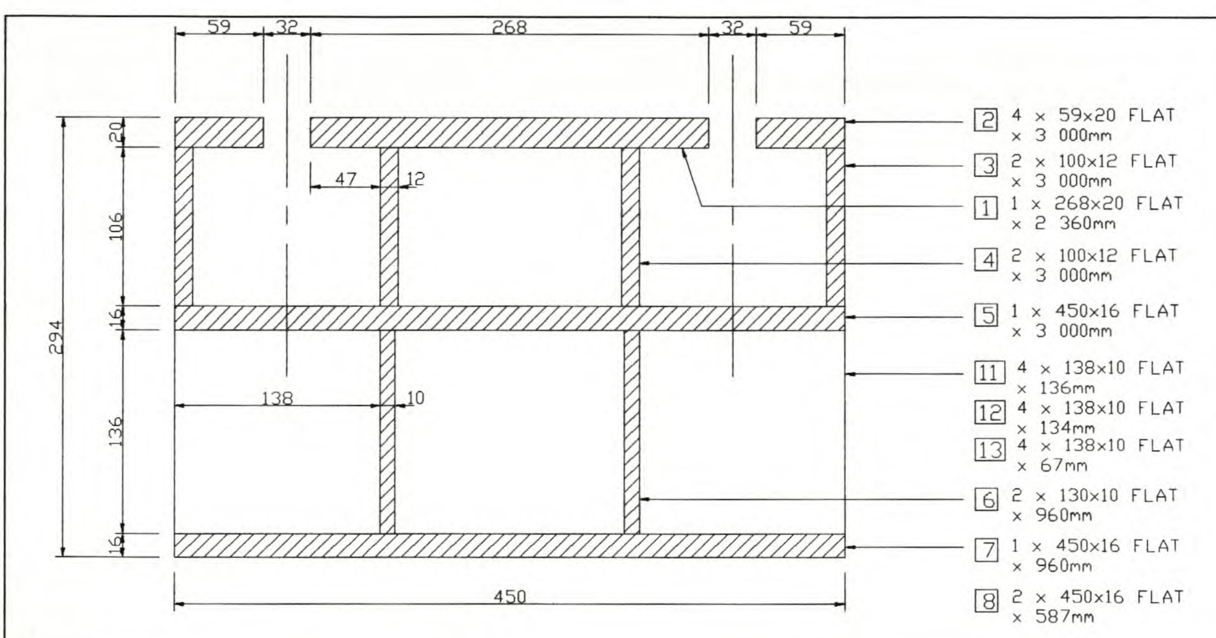


Figure 4-5 Typical Cross section through the 500 kN Actuator Bridge

The cross centres of the grooves of the loading bridges match the grooves of the tracks, providing greater flexibility in the use of the loading equipment.

The bridges are connected to the tracks via a hinge, which was designed to eliminate torsion on the tracks. The hinges enable the bridge to be shifted along the tracks so that a point load can be applied at any position between or along the tracks, using the servo hydraulic actuator.

The hinge consists of a base plate with 4 vertical flanges. Pins and bushes are used to create a true simply supported end for the loading bridge. This allows the ends of the load bridge to rotate resulting in pure vertical load transferred to the tracks. The load bridge, hinge and track connection is illustrated in Figure 4-6.

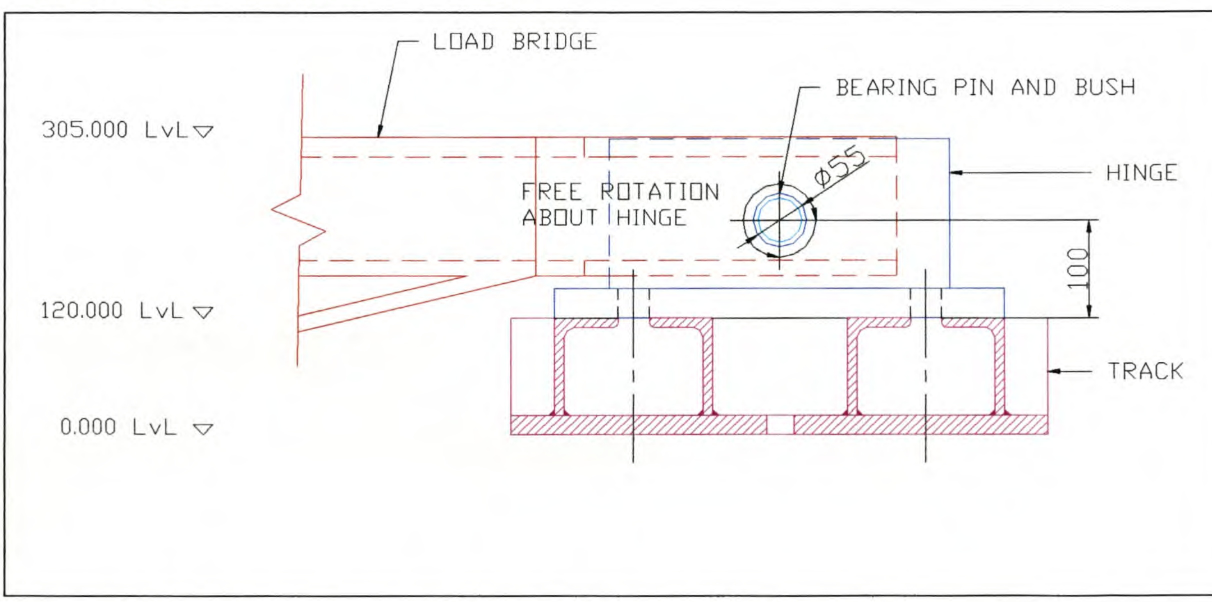


Figure 4-6 The Hinge connecting the Load Bridge to the Track

Although the load bridges were not designed as end supports, it is possible to provide support to the test specimen. This can be achieved by bolting any supporting structure to the load bridge by means of the grooves and will be illustrated later.

[For the design of the tracks refer to Appendix C.2.2.2 and C.2.2.3 and for detail drawings to drawings 03-3D-01, 03-3D-02, 03-01/1, 03-01/2, 03-01/3, 03-02/1, 03-02/2 and 03-02/3 in Appendix A]

4.5 The End Supports

The end support consists of two parts namely the horizontal bridges and the vertical support frame sections as illustrated in Figure 4-1 and Figure 4-7.

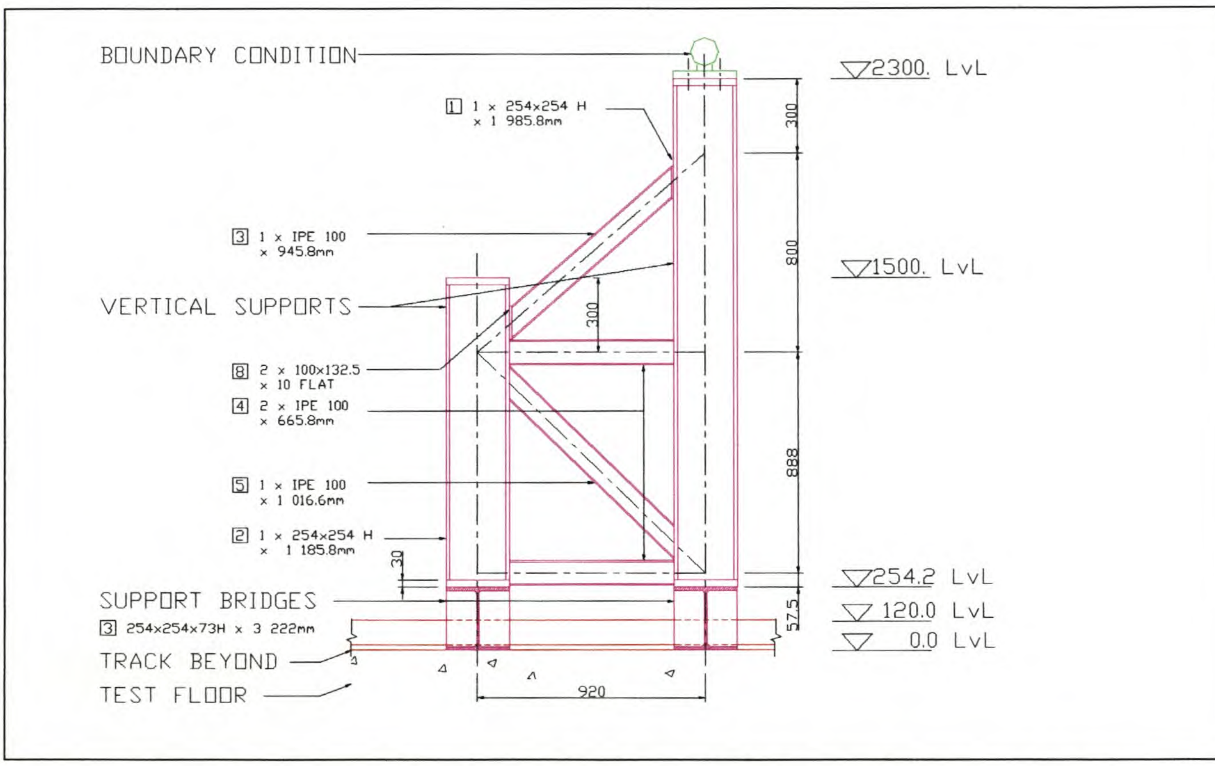


Figure 4-7 The End Supports consisting of a Horizontal Bridge and a Vertical Frame

The support bridges are made up of notched 254x254x73 H sections. The vertical support frames are bolted to the support bridges. To save costs, the support bridges have holes at 127 mm centres instead of having grooves for the vertical support frame. This means that the vertical end support can only be bolted on at discrete positions. This will prove to be more than adequate due to the close spacing of these holes and the overall width of the support. .

The support bridges are bolted to the tracks and are guided along them similar to the load bridges, making it possible to test beams of various lengths. When the load is applied to the supports in the negative Y' direction (towards the test floor), the load bridges will bear directly on the test floor to ensuring maximum load capacity as can seen in Figure 4-8. In the case of an applied load in the positive Y' direction, the tracks will provide restraint against uplift. The support bridges are also sufficiently stiff so that the deflection of the bridges can be ignored.

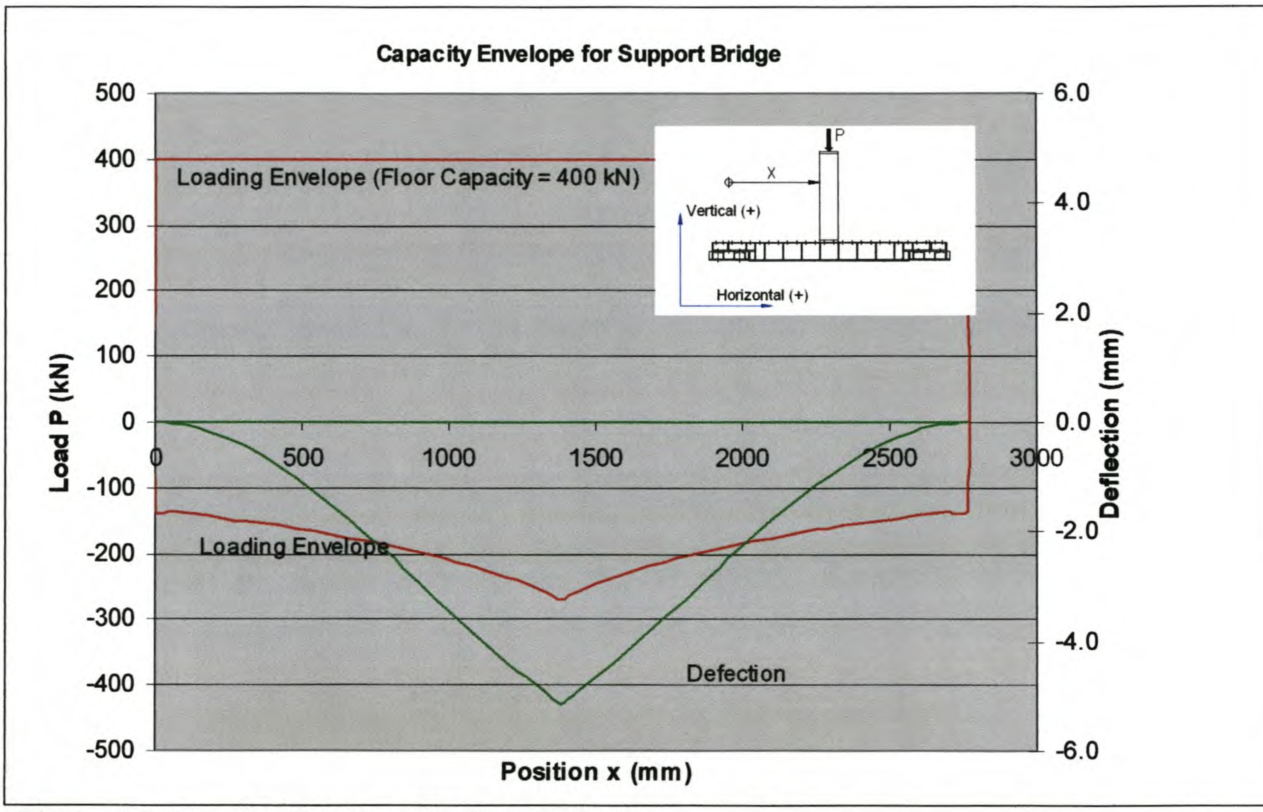


Figure 4-8 Capacity Envelope for Support Bridge

The vertical support frame consists of 2 vertical 254x254x73 H section members braced together with IPE 100 I- beams. The vertical elements, being of different lengths, provide for testing at two levels, namely the 1.5 m and the 2.3 m level. The ability to test at two levels provide for further flexibility as a combination of transfer beams and other loading equipment can be used.

The cross bracing is required for when axial forces are applied to the beam. In the case of no horizontal forces, and small vertical loads, the cross bracing can be omitted. More than one vertical frame can be bolted to the support bridges making it possible to test beams of various widths, or to ensure for a stiffer support. The frames can also be bolted back to front to provide for the testing of cantilevers. This will be illustrated in section 4.7.

The required boundary conditions are bolted to the vertical frame at either the 1.5 m level or the 2.3 m level, as illustrated in Figure 4-7. This allows the boundary conditions to be changed to match the requirements of each test.

The end supports were designed to provide a vertical reaction of 600 kN and a horizontal reaction of 50 kN acting as an axial load on the beam without any adjustments to the support. The loading and deflection capacity diagram of the unadjusted support for unfactored loads are given in Figure 4-9, Figure 4-10 and Figure 4-11 for testing at the 1.5 m level and in Figure 4-15, Figure 4-16 and Figure 4-17 for testing at the 2.3 m level.

By making minor adjustments to the support, the lateral load can be increased to 200 kN. These adjustments entail the removal of the diagonal brace and propping at the 2.3 m level in the case of testing at the 1.5 m level. For testing at the 2.3 m level the 1.5 m level needs to be extended and propped. The propping can easily be achieved by connecting the two end supports. This can be done using a tension member when testing the beam for compression or a compression member when tension forces are applied to the beam. The loading and deflection capacity diagram for the adjusted support is given in Figure 4-12, Figure 4-13 and Figure 4-14 for testing at the 1.5 m level and in Figure 4-18, Figure 4-19 and Figure 4-20 for testing in the 2.3 m level.

The user needs to verify that the applied loads falls within the capacity of the support. As an example, testing at the 1.5 m level and a maximum (negative) vertical load of 2030 kN can be applied together with an (-) 80 kN horizontal load.

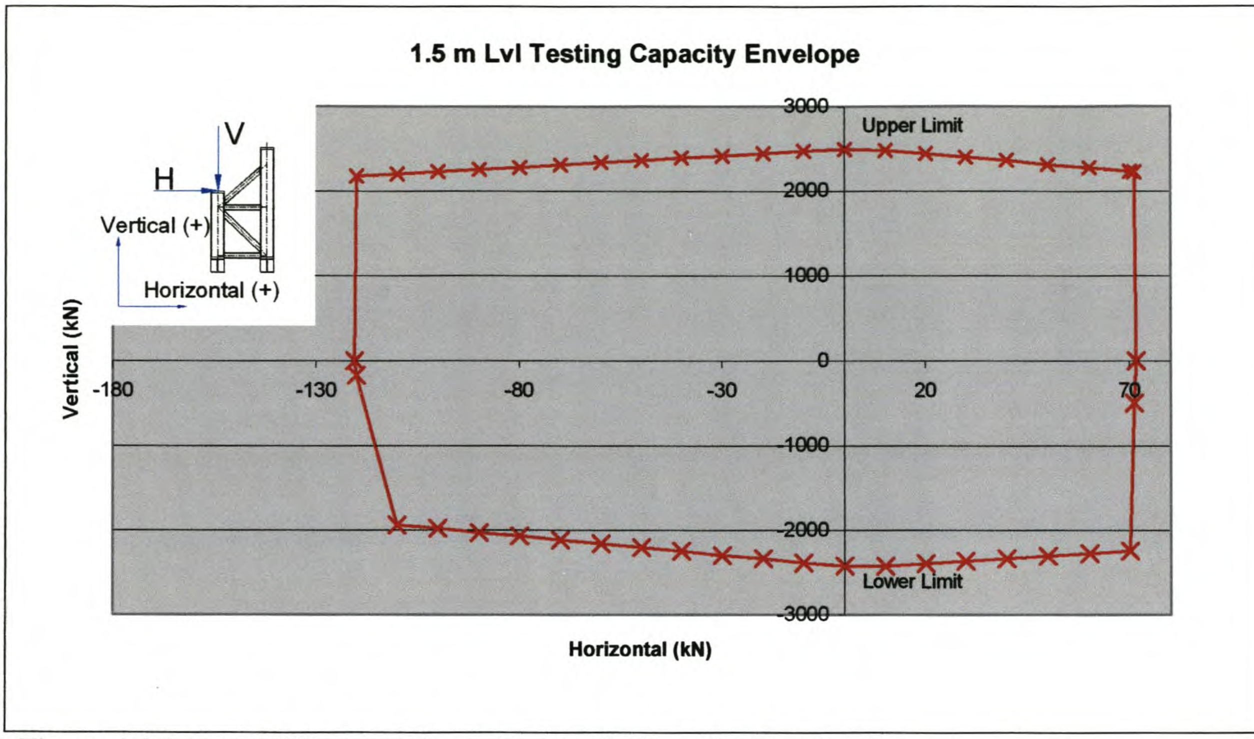


Figure 4-9 1.5 m Lvl Support Capacity: Load Capacity Envelope

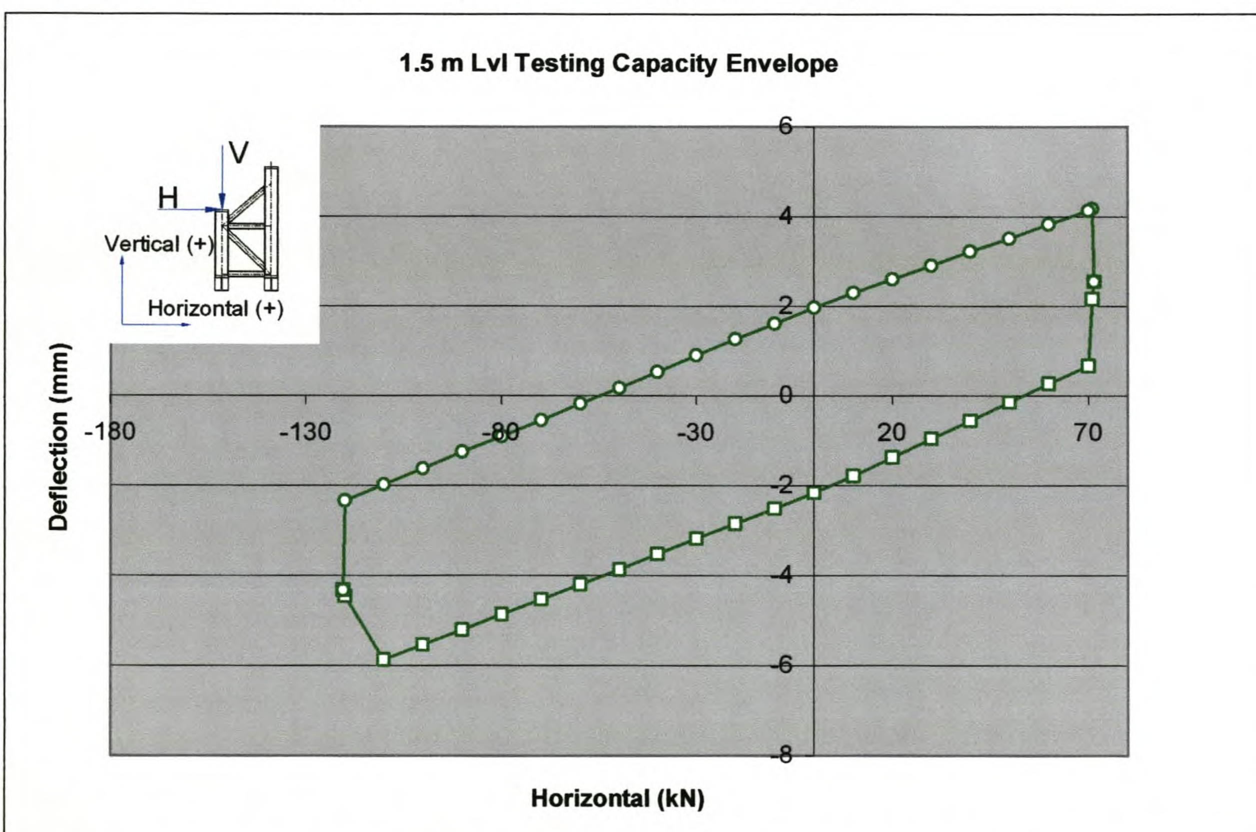


Figure 4-10 1.5 m Lvl Support: Horizontal Deflection Capacity Envelope

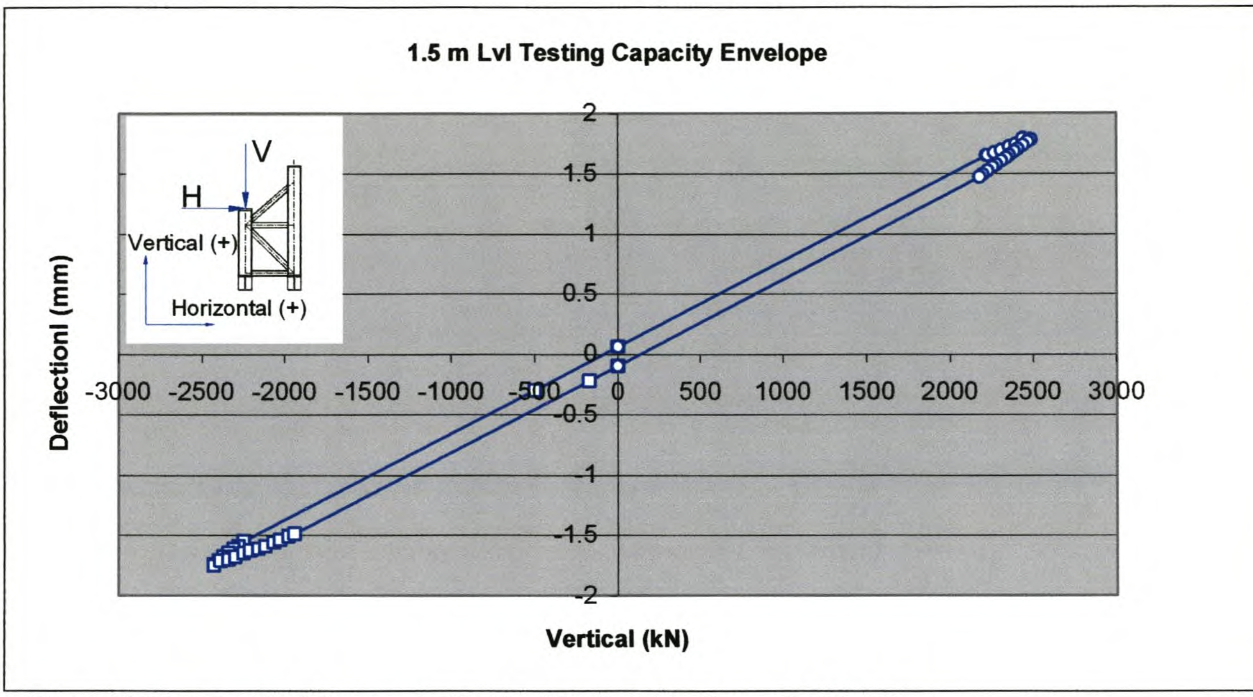


Figure 4-11 1.5 m Lvl Support: Vertical Deflection Capacity Envelope

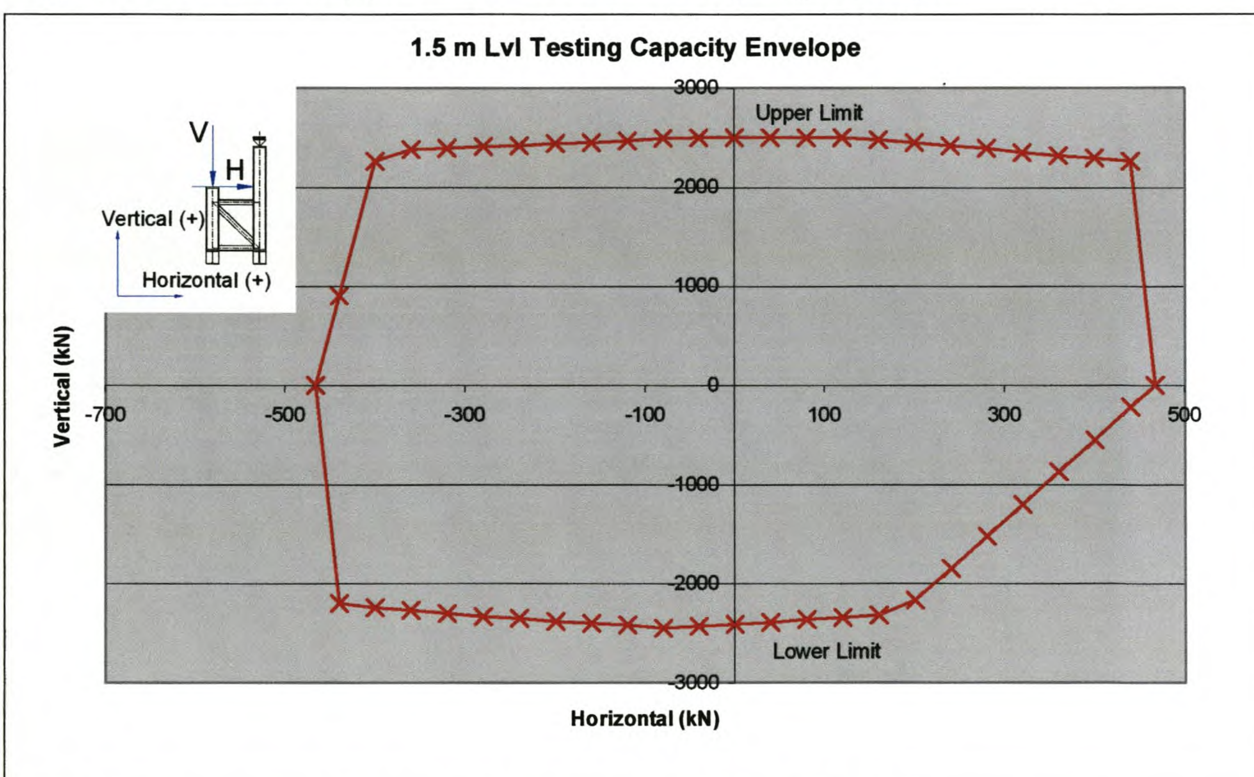


Figure 4-12 1.5 m Lvl Adjusted Support: Load Capacity Envelope

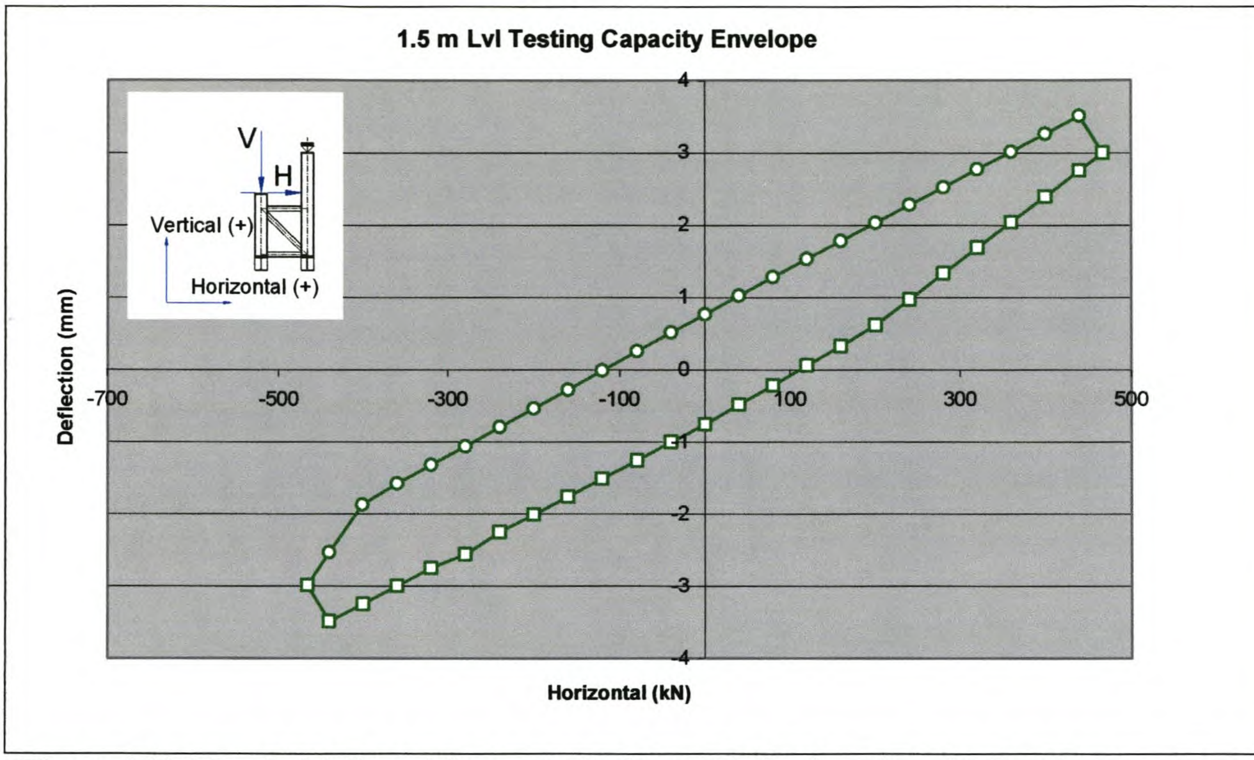


Figure 4-13 1.5 m Lvl Adjusted Support: Horizontal Deflection Capacity Envelope

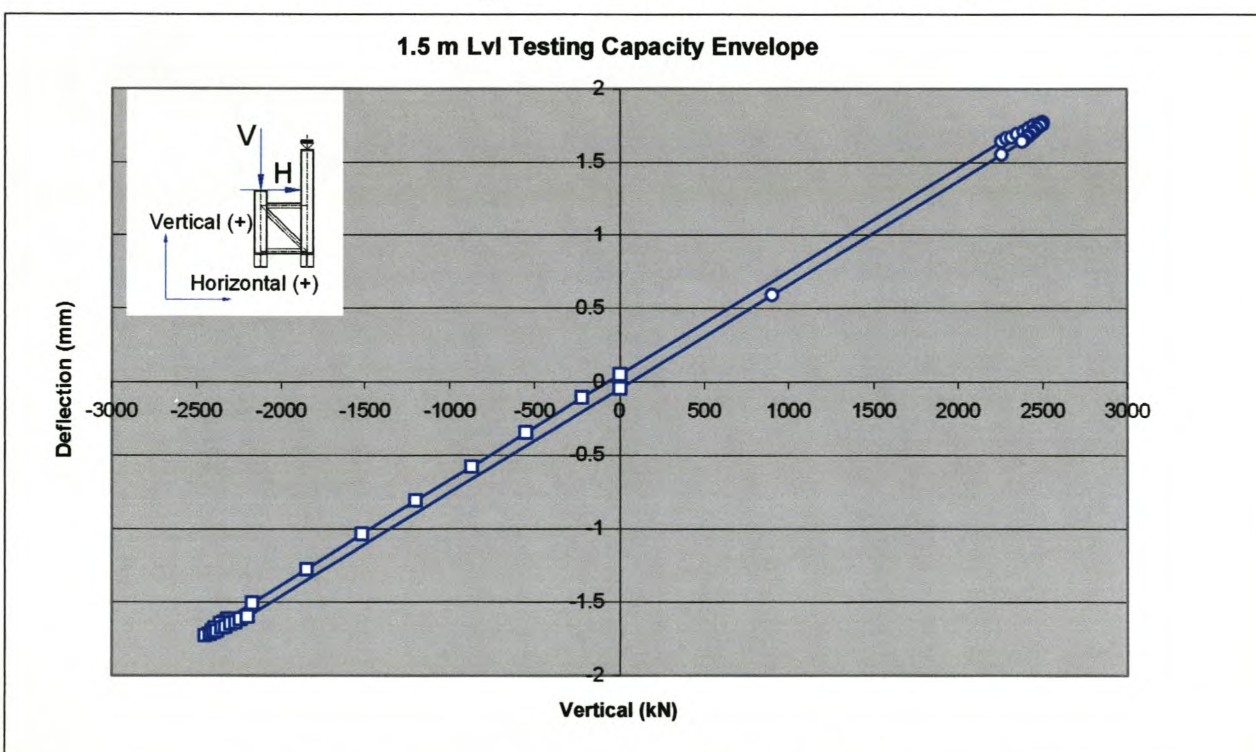


Figure 4-14 1.5 m Lvl Adjusted Support: Vertical Deflection Capacity Envelope

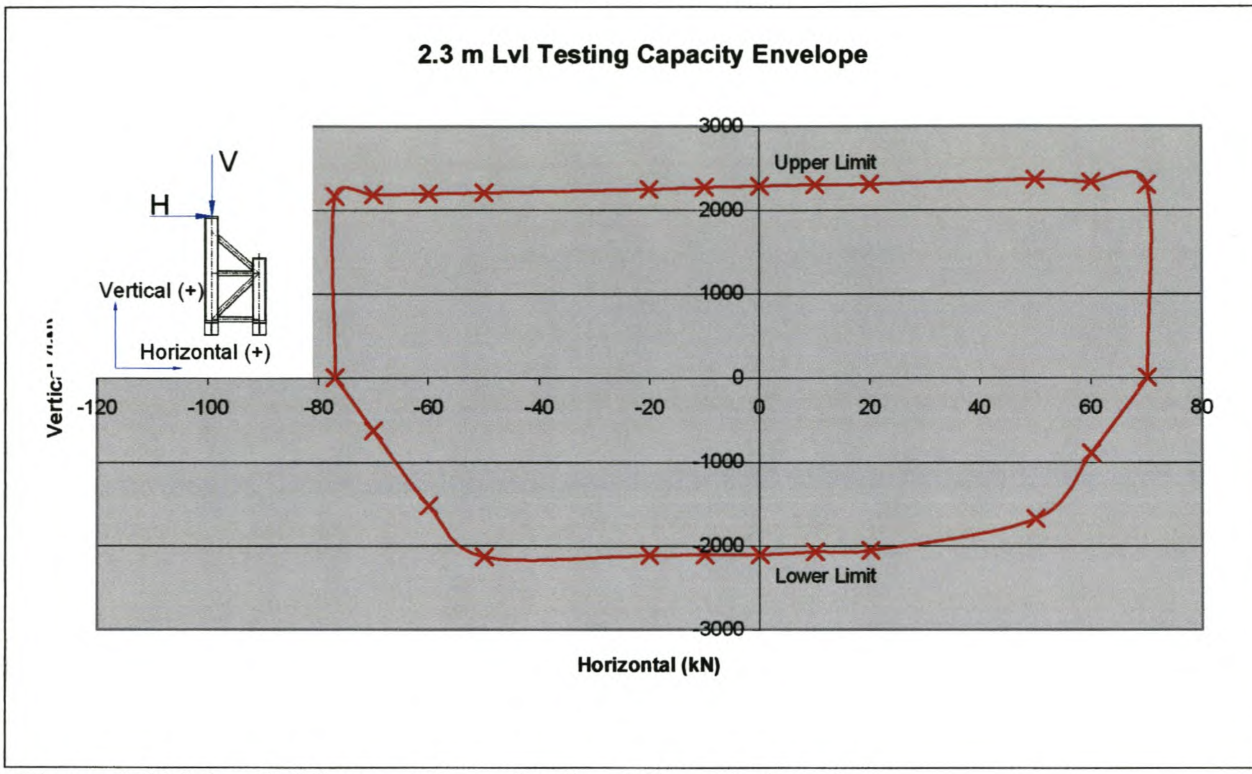


Figure 4-15 2.3 m Lvl Support Capacity: Load Capacity Envelope

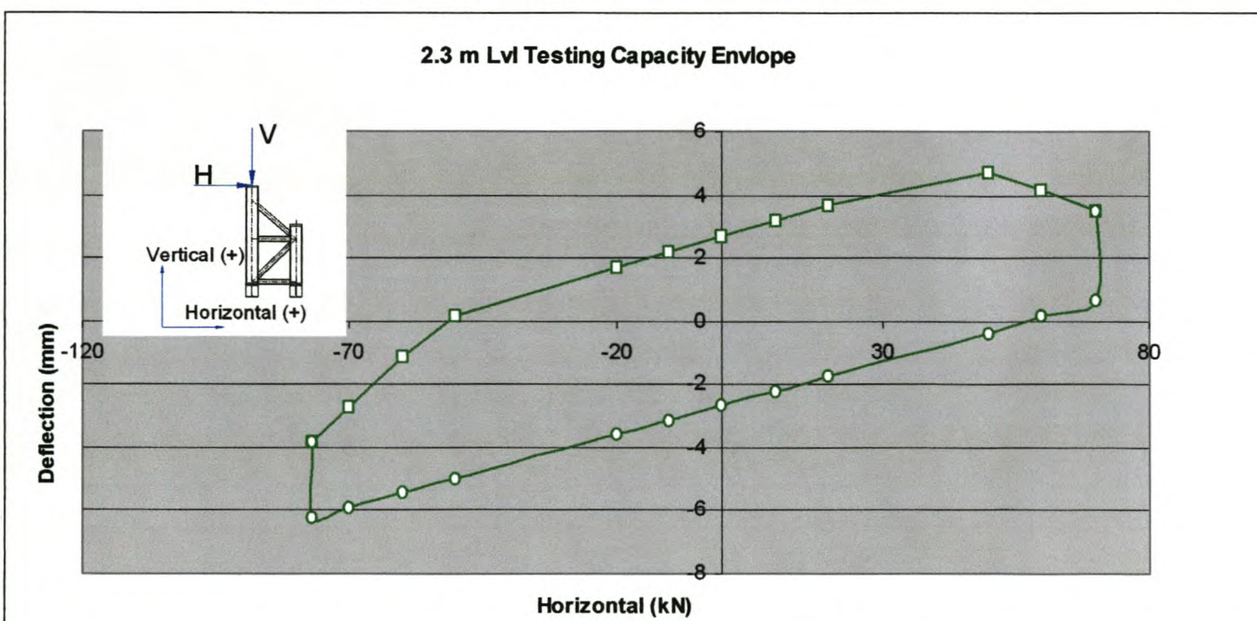


Figure 4-16. 2.3 m Lvl Support: Horizontal Deflection Capacity Envelope

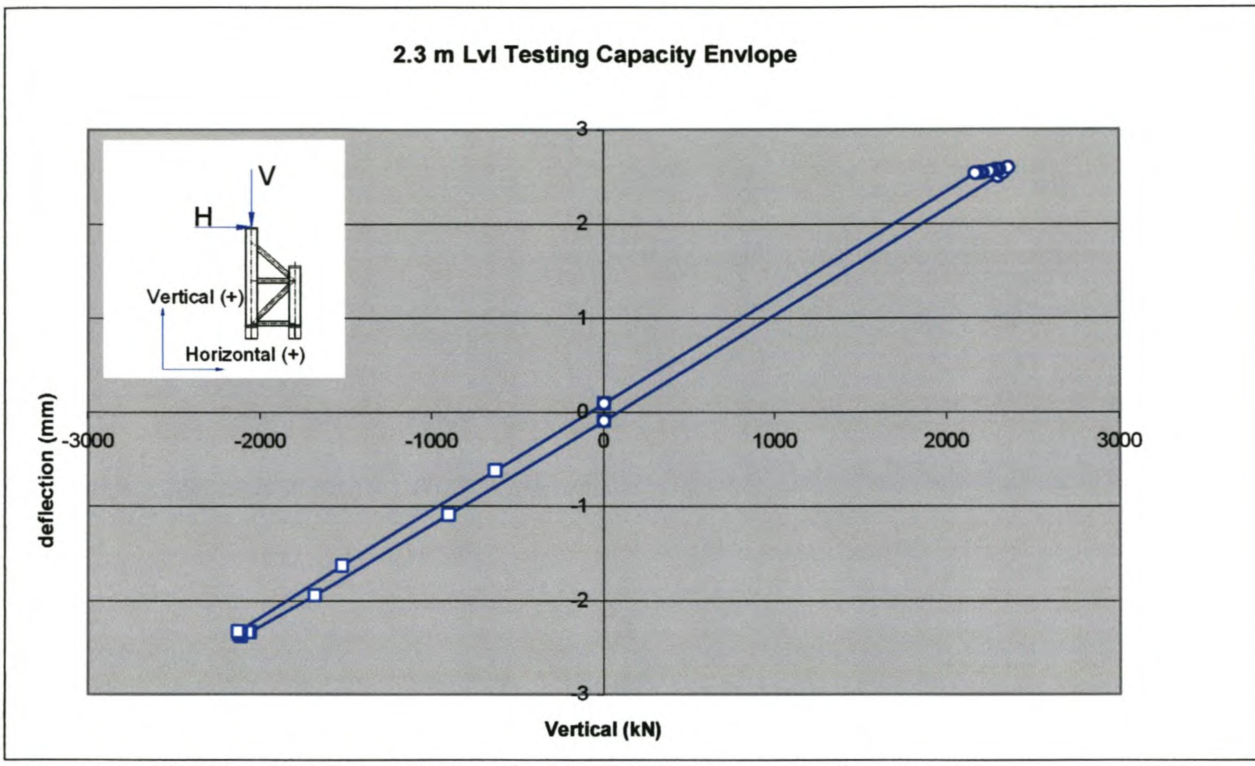


Figure 4-17. 2.3 m Lvl Support: Vertical Deflection Capacity Envelope

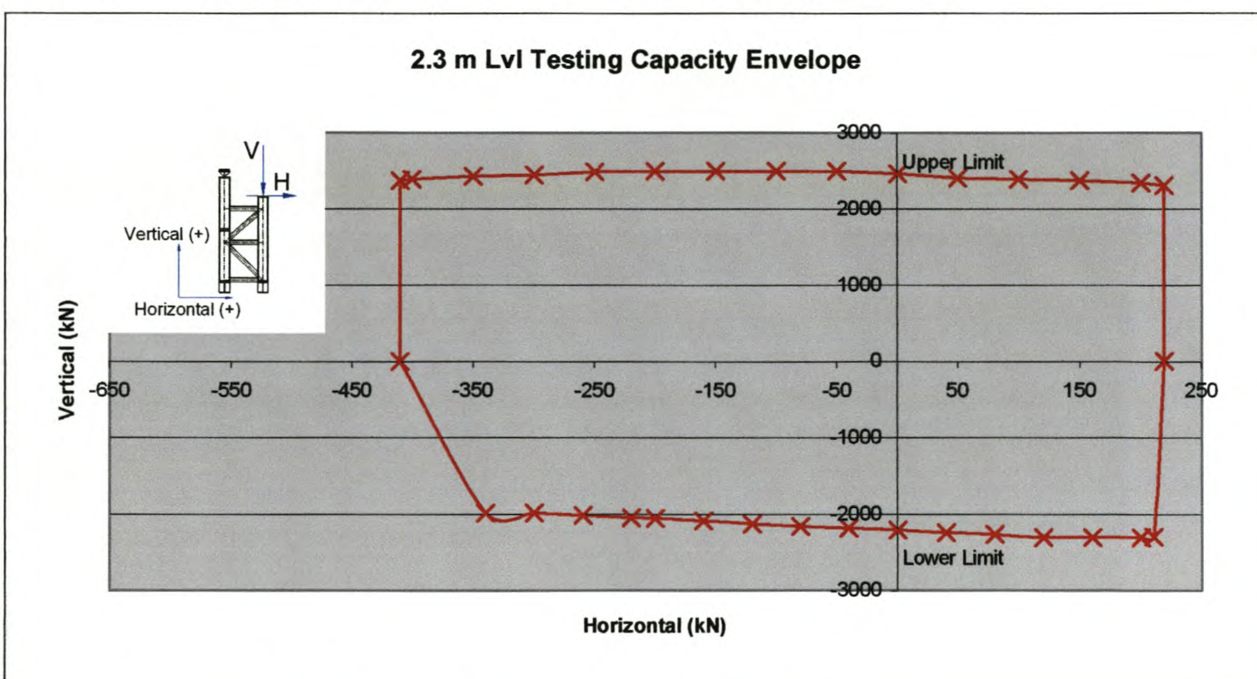


Figure 4-18 2.3 m Lvl Adjusted Support: Load Capacity Envelope

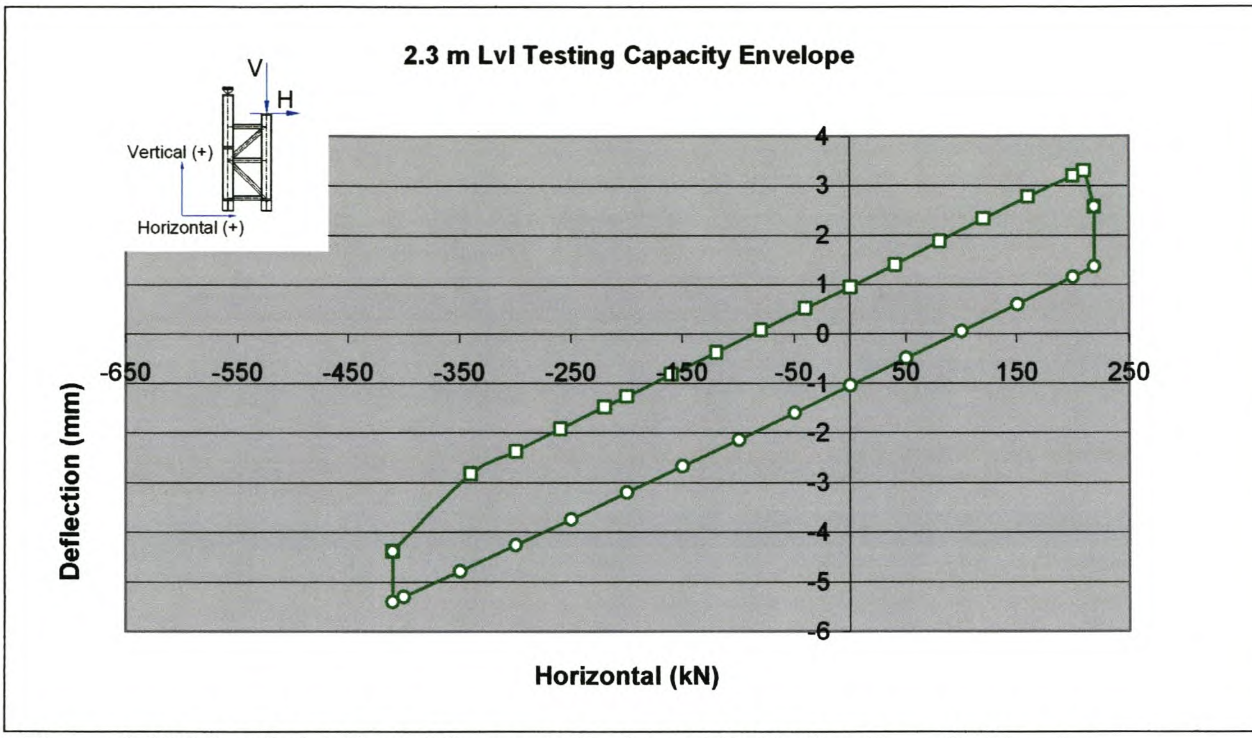


Figure 4-19 2.3 m Lvl Adjusted Support: Horizontal Deflection Capacity Envelope

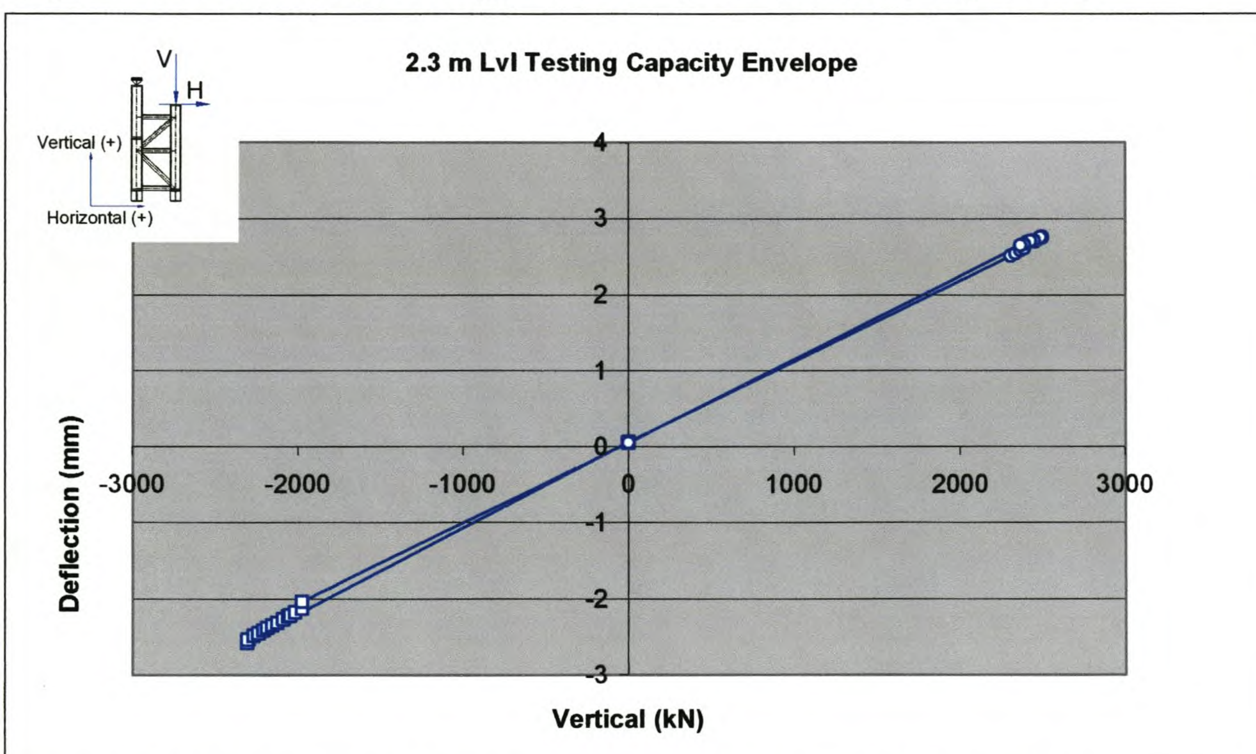


Figure 4-20 2.3 m Lvl Adjusted Support: Vertical Deflection Capacity Envelope

Two end supports can be fixed side to side to minimize the deflection of the supports as the loads are shared. When testing for horizontal loads it is required that the supports be not only fixed to the tracks but also to the test floor so that slip of the supports can be prevented. This can be done by means of a tension cable and will be illustrated later.

When testing a cantilever beam, the two supports are bolted back to front and the 2.3 m levels connected by a member of at least equal stiffness to the cantilever beam (and will be illustrated later). The loading capacity for testing cantilevers and the deflection thereof is illustrated in Figure 4-21 and Figure 4-22.

Similar to the vertical and horizontal capacity charts, the moment capacity diagrams gives the maximum unfactored loads and the rotation and displacement capacity of the support. As an example, a moment of 260 kNm together with a shear force of (-) 1100 kN can be applied using a point load. The maximum rotation of the point of loading would then be 0.00325 radians.

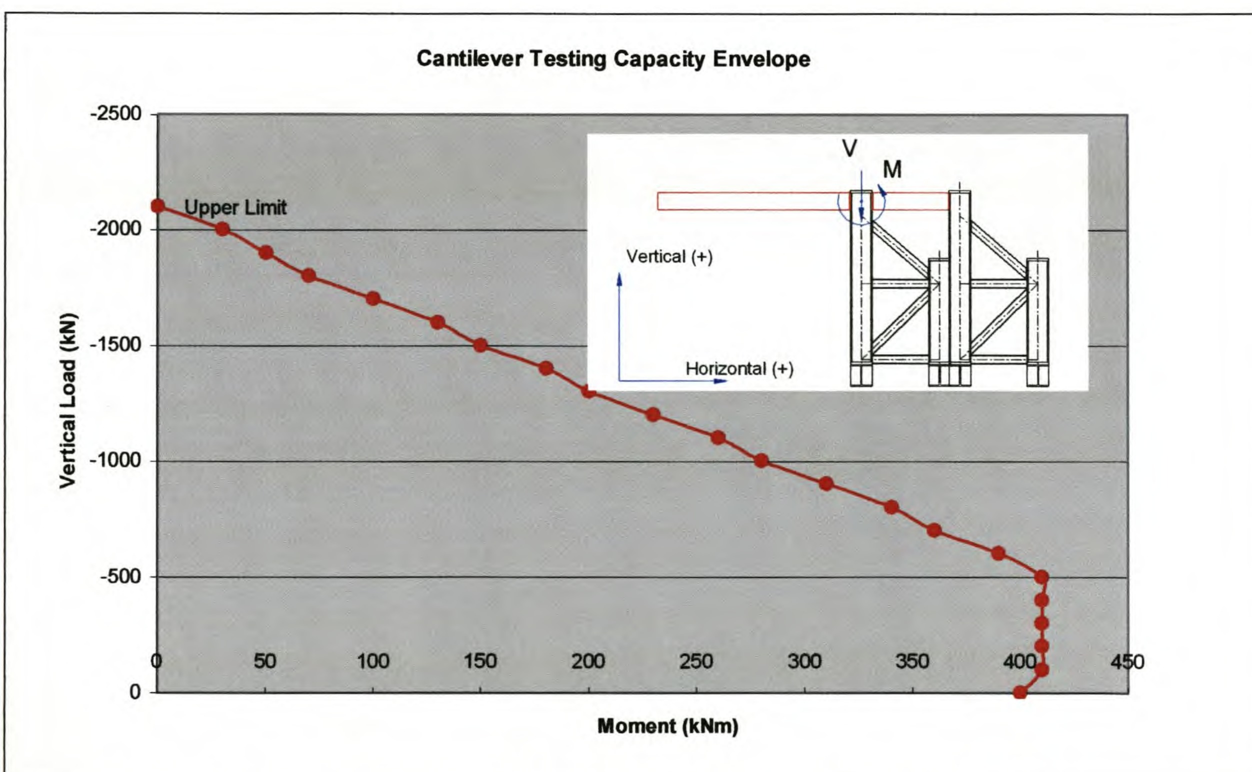


Figure 4-21 Support Capacity for Cantilever Testing: Displacement of Support

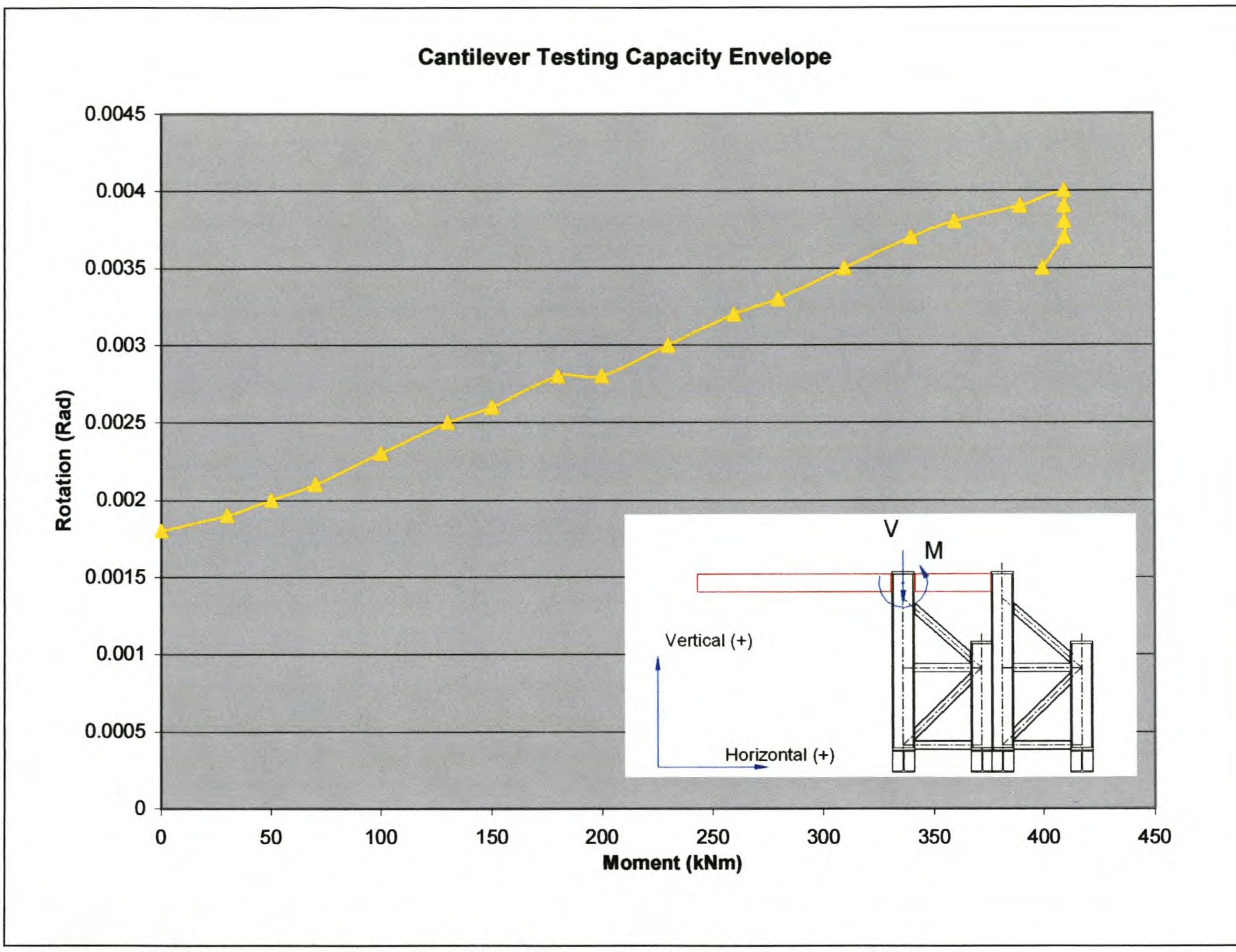


Figure 4-22 Support Capacity for Cantilever Testing: Rotation of Support

The load capacity of the supports exceeds the capacity of the test floor in most cases and is therefore not critical. It is important to verify that the deflection of the support is within testing limits. In most cases the deflection of the support is small compared to the overall length or deflection of the test piece and can be ignored.

[For the design of the supports and the origin of all the figures in this section refer to Appendix C.2.4. For the detail drawings refer to drawings 04-3D-01, 04-01/1, 04-01/2, 04-02/1 and 04-02/2 in Appendix A]

4.6 Lateral Supports

Lateral support and lateral loading are achieved by means of a portal frame and a lateral supporting or loading mechanism. The supporting frames are designed so that various lateral supporting mechanisms such as the Watt-mechanism, cable systems, rod systems or guide tracks (as discussed in chapter 2) can be used to provide lateral support as required.

The supporting frame is illustrated in Figure 4-1 and Figure 4-23 and is made up of IPE 200 sections. The frame is connected to the tracks, loading bridge or the support bridge by means of a connector and to the guide track at first floor level. Three different connectors were designed for connecting the frame to the tracks, loading bridge or the support bridges to ensure that the frame heights remain constant.

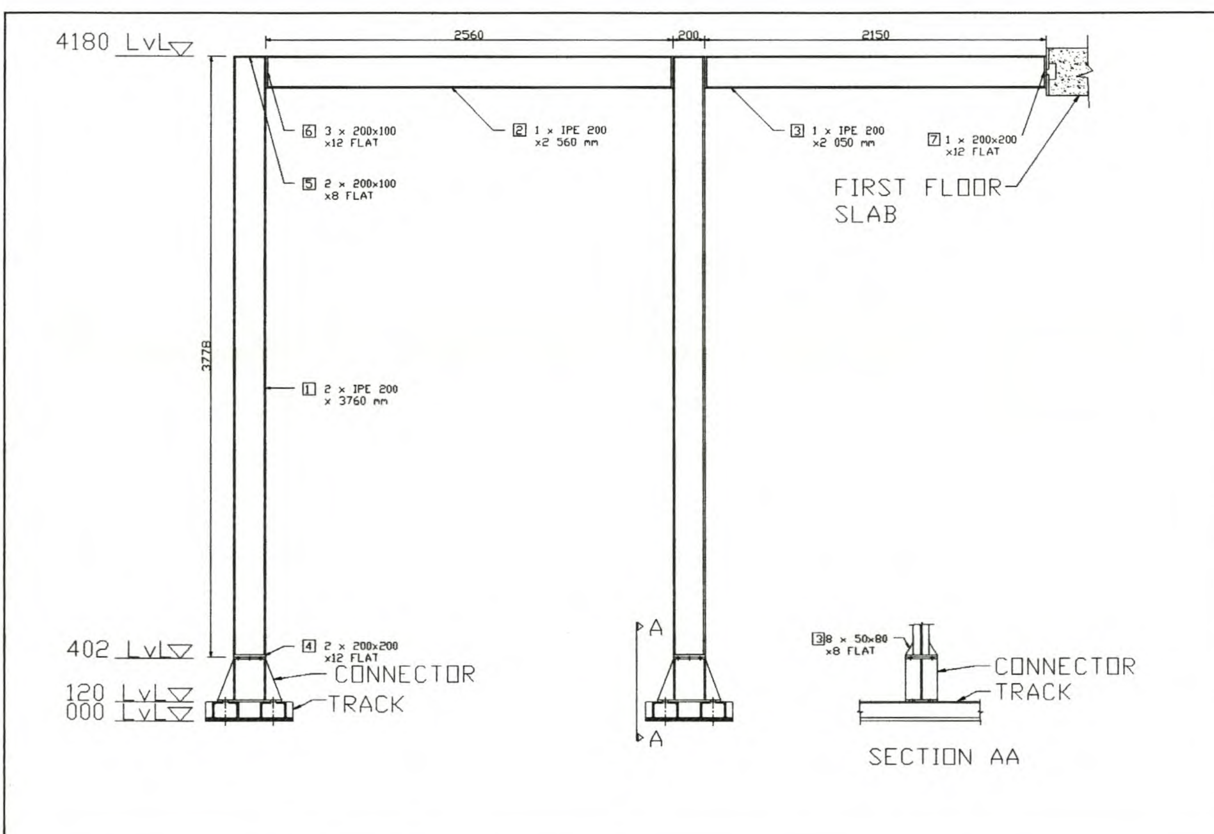


Figure 4-23 The Lateral Supporting Frame

The lateral support frame was designed to resist a horizontal load of 25 kN on each vertical column leg of the frame. The load capacity for the unadjusted lateral support frame is given in Figure 4-24 and the deflection envelope is given Figure 4-25. As an example a maximum factored lateral load of 62.5 kN can be applied at a height of 3.3 m. For the deflection of the frame under various loads at various heights refer to Figure 4-26.

Using a tie brace to an anchor point on the floor or rod at 45° the lateral force will be transferred directly to the test floor, resulting in an increase of the load capacity of the lateral support frame. The load capacity for the lateral support frame using a tie brace or rod is given in Figure 4-27.

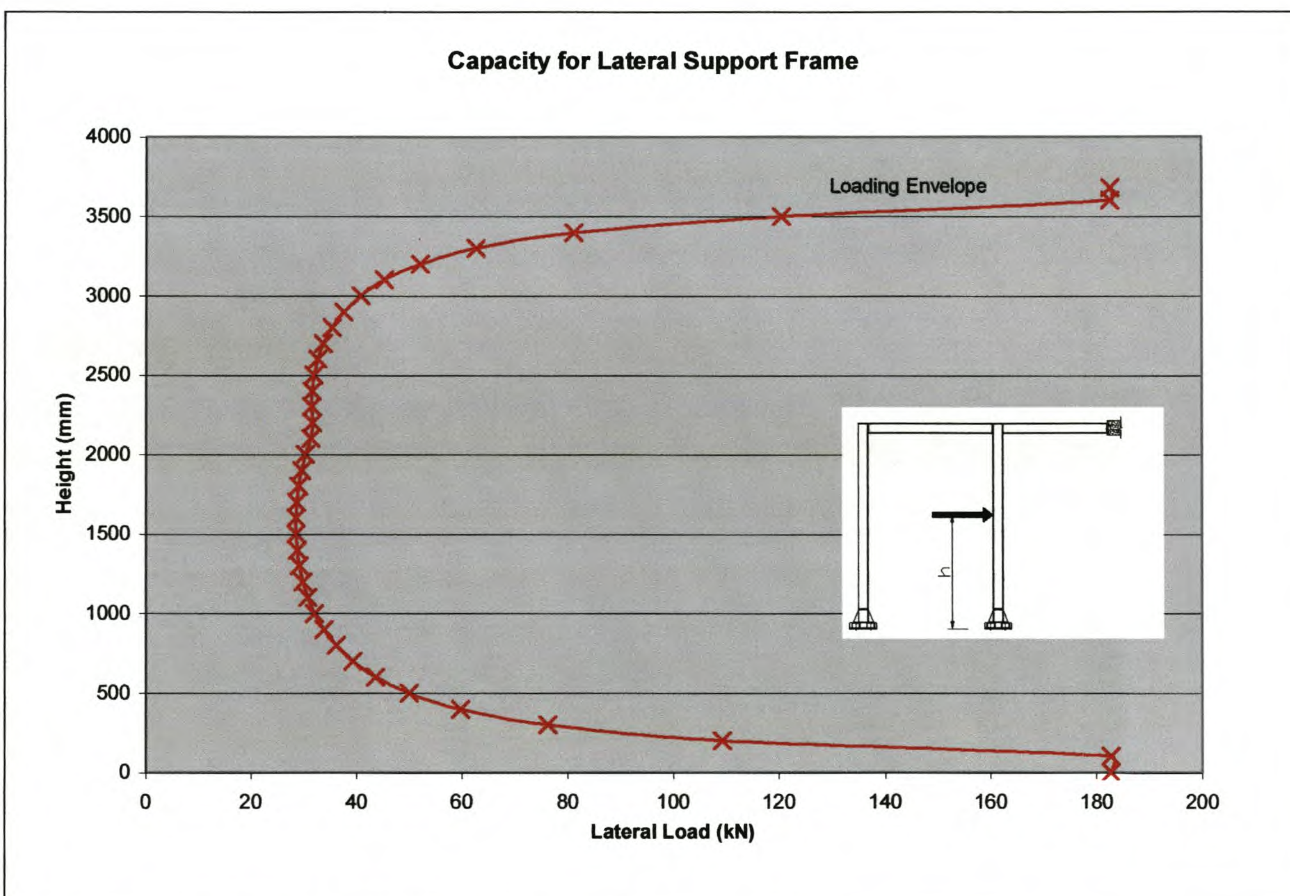


Figure 4-24 Loading Capacity of the Lateral Support Frame

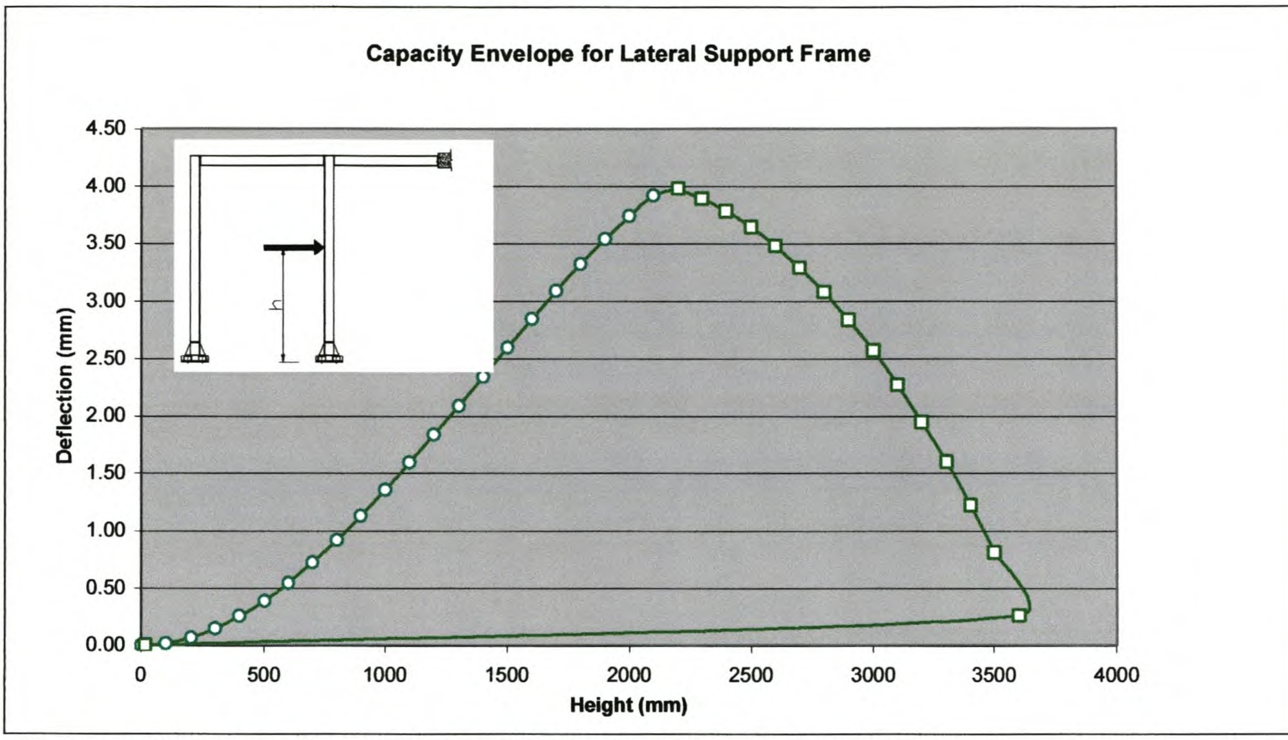


Figure 4-25. Lateral Support Frame: Deflection Capacity Envelope

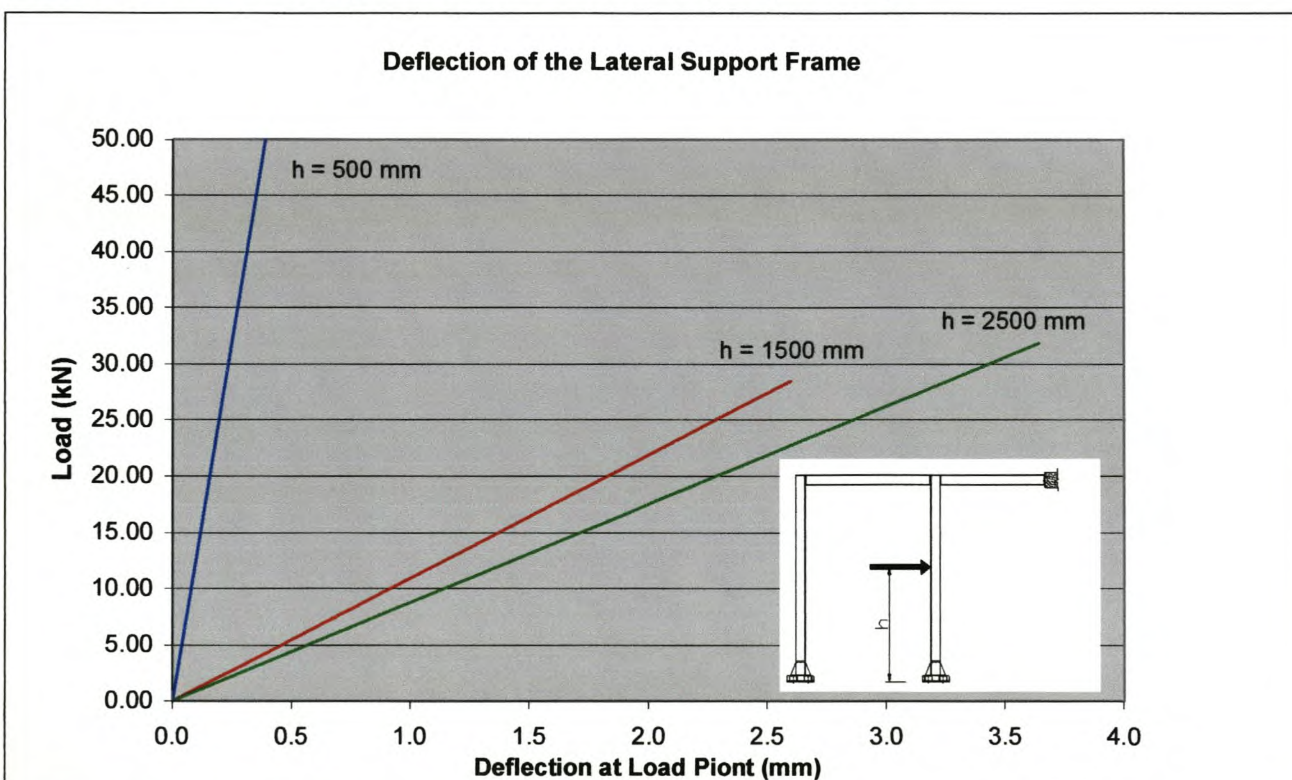


Figure 4-26. Deflection of the Lateral Support Frame

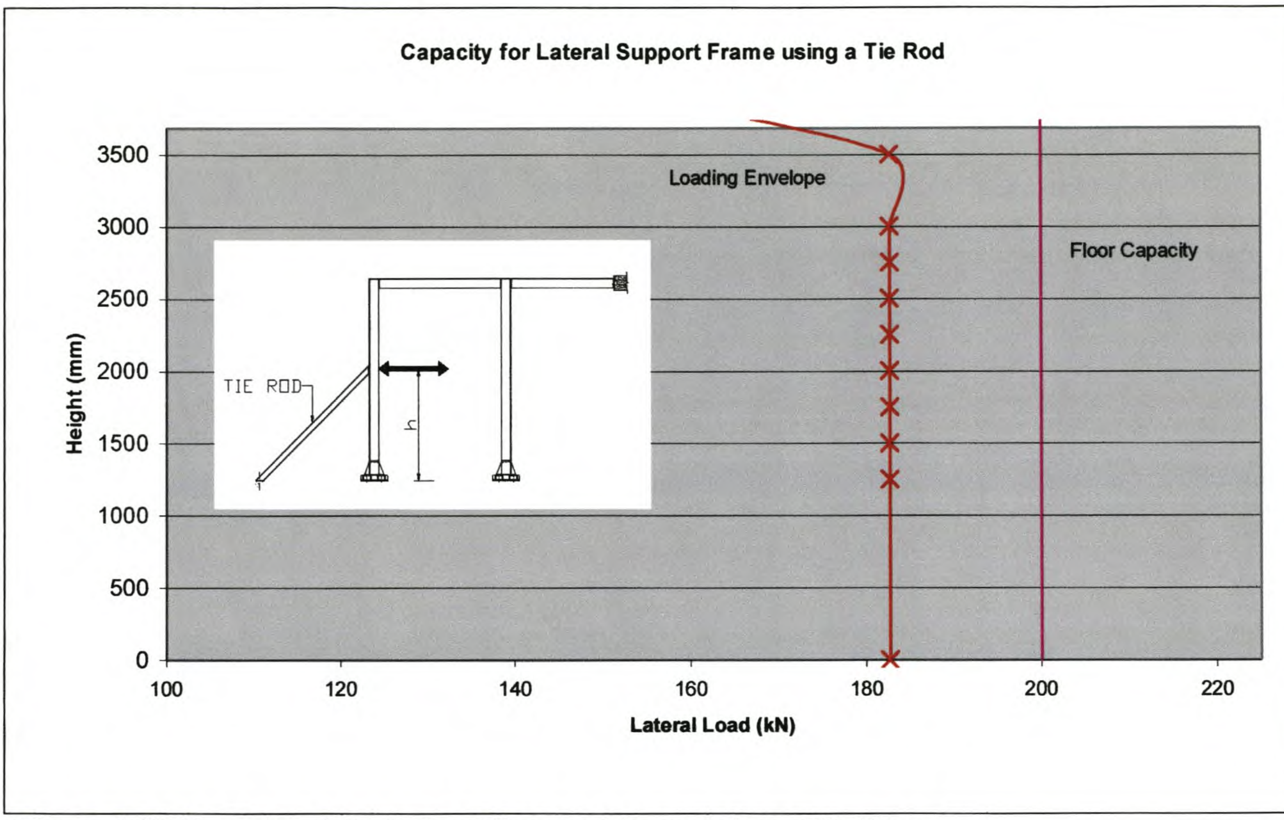


Figure 4-27 Capacity of the Lateral Support Frame using a Tie Brace

When using a lateral support mechanism such as a rod, one of the vertical columns of the frame can be removed as only a single fixing point is required for the mechanism. This will be illustrated in the following section.

The use of the lateral support frame, using various connectors and lateral supporting mechanisms, will be illustrated in the following section.

[For the design of the lateral supports frames and the origin of all the figures in this section refer to Appendix C.2.5. For the detail drawings to refer to drawings 05-3D-01, 05-01/1 and 05-02/2 in Appendix A]

4.7 Test Arrangements using the MTA

In this section the versatility of the MTA will be demonstrated by means of a number of test examples. The testing of different test samples, including beams, trusses and slabs, of various sizes, under different boundary conditions and testing at different heights will be illustrated in these test examples.

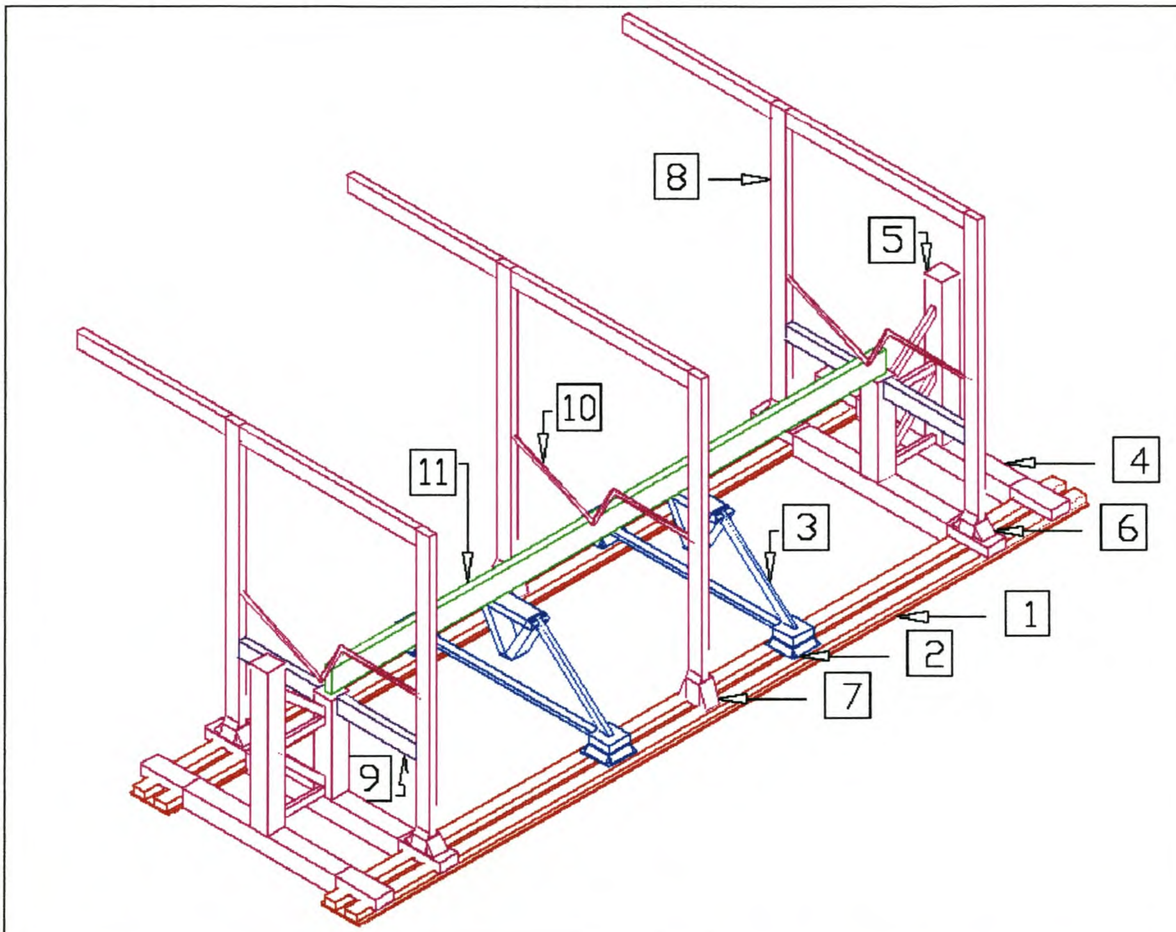
The use of the different load bridges to apply a vertical load and the application of axial (tension and compression) and lateral loads will also be illustrated. The versatility of the lateral support frames in providing lateral support will be illustrated with the use of the different types of lateral supporting mechanism to provide lateral support or to apply lateral loads.

[These graphical test examples were created by means of cross-referenced three-dimensional object drawings. For more details on these drawings and the use of the 3D OBJECT drawings to create visual displays in two and three dimensions refer to Appendix A.]

4.7.1 Test Setup: Example 1 - Testing a Simply Supported Beam

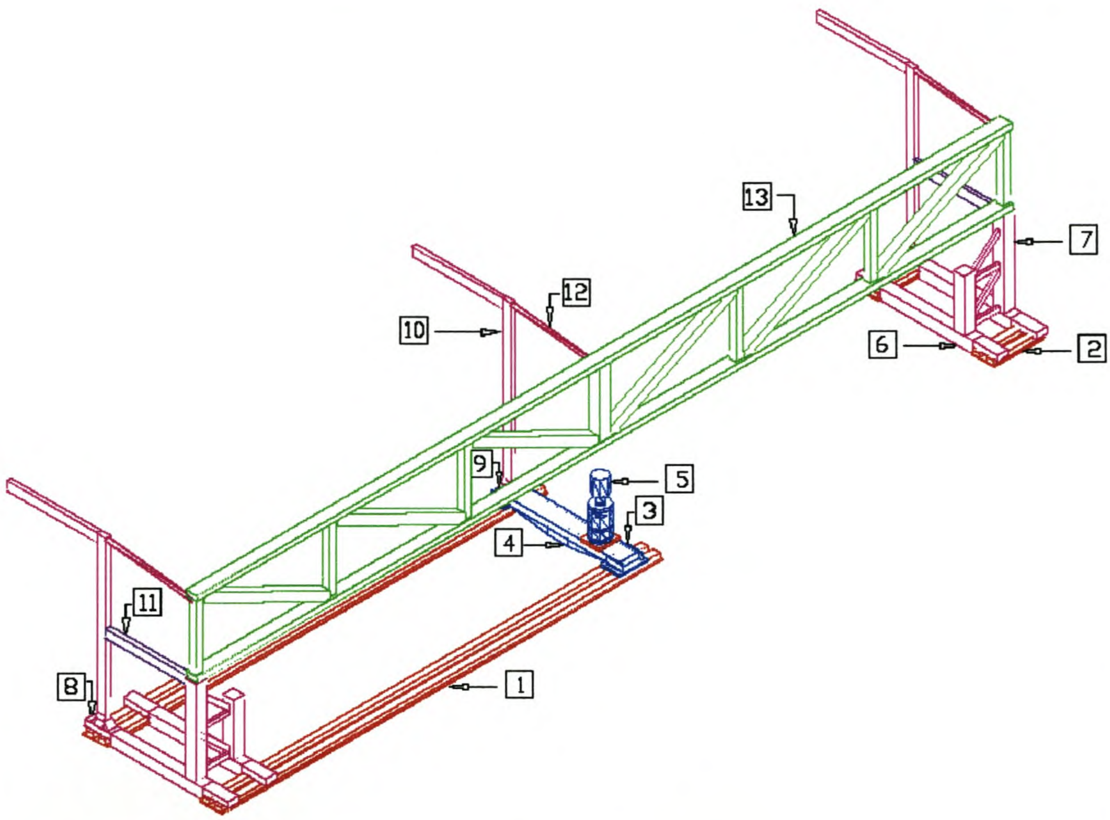
In example 1, as illustrated in Figure 4-28, a simply supported beam is tested at the 1,5m level. Vertical loads (loading in the Y direction) are applied at third points using the gravity load simulators, to ensure a constant bending moment over the central third of the beam (refer to section 2.5.2 for more information on this setup).

As the gravity load simulators are mainly used to test structures permitted to sway, no lateral support would be required at the loading points. Lateral support is however provided at mid span and at the support using a Watt-mechanism.



1.	Tracks	7.	Lateral Support Frame / Track Connector
2.	Gravity Simulator Track Connector	8.	Lateral Support Frame
3.	Gravity Simulator	9.	Lateral Support Brace
4.	Horizontal Support Bridge	10.	Watt-mechanism
5.	Vertical Support	11.	Beam
6.	Lateral Support Frame / Support Connector		

Figure 4-28 Test Setup: Example 1 - Testing a Simply Supported Beam



1. Tracks	8. Lateral Support Frame / Support Connector
2. Secondary Tracks	9. Lateral Support Frame / Load Bridge Connector
3. Hinge	10. Lateral Support Frame
4. 500 kN Load Bridge	11. Lateral Support Brace
5. 500 kN Servo Hydraulic Actuator	12. Rod
6. Horizontal Support Bridge	13. Truss
7. Vertical Support	

Figure 4-29 Test Setup: Example 2 – Testing a Truss

4.7.2 Test Setup: Example 2 – Testing a Truss

When testing beams or trusses with lengths greater than 10 m, the tracks can be rotated 90 degrees, so as to run along the length of the test floor. Shorter secondary tracks are then used to connect one end support at the end of the test floor as illustrated in Figure 4-29.

In this example the 500 kN servo hydraulic actuator is used together with the 600 kN load bridge to apply a vertical load at mid span of the truss.

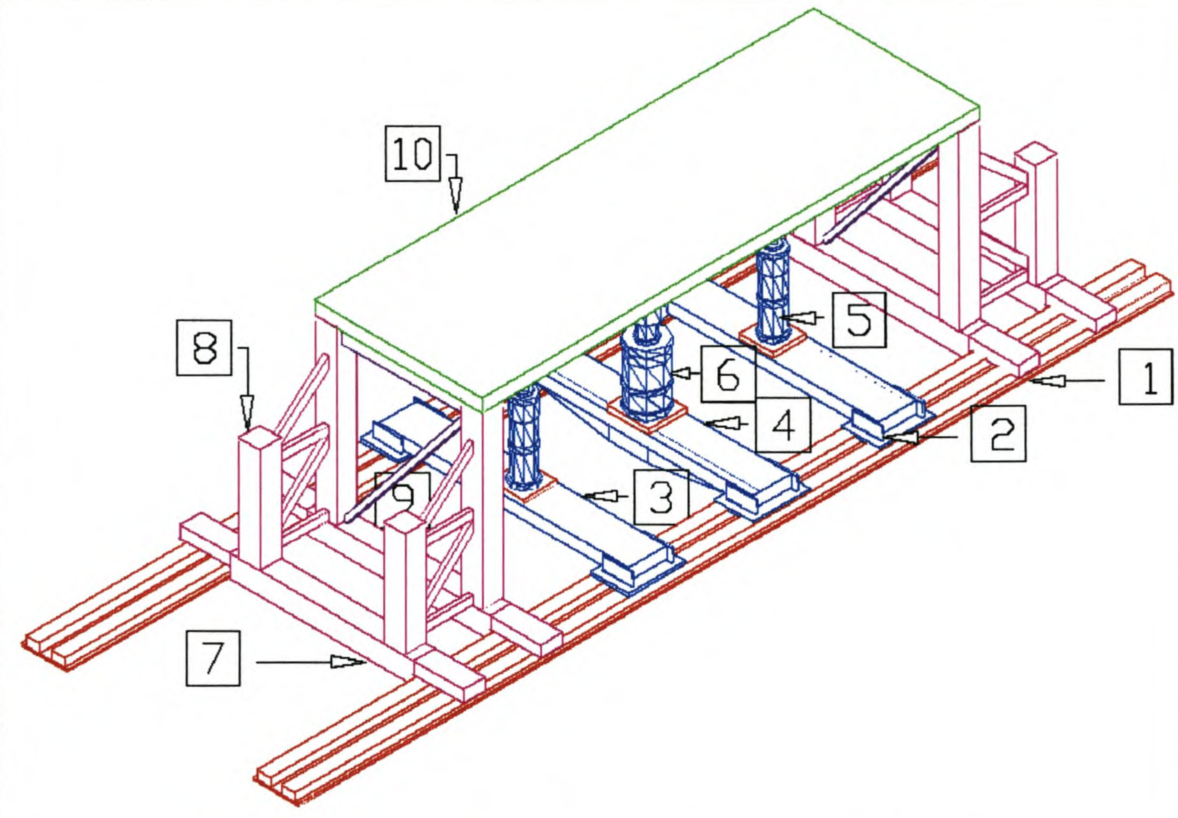
When a lateral supporting mechanism with a single fixing point is used, the lateral frame can be adjusted as illustrated in Figure 4-29. In this example a rod is used to provide lateral support at the supports and at mid span.

The truss, supports and servo hydraulic actuator are offset from the centre line (the Z-axis) between the tracks to allow for the use of a longer rod.

4.7.3 Test Setup: Example 3 – Testing a Slab

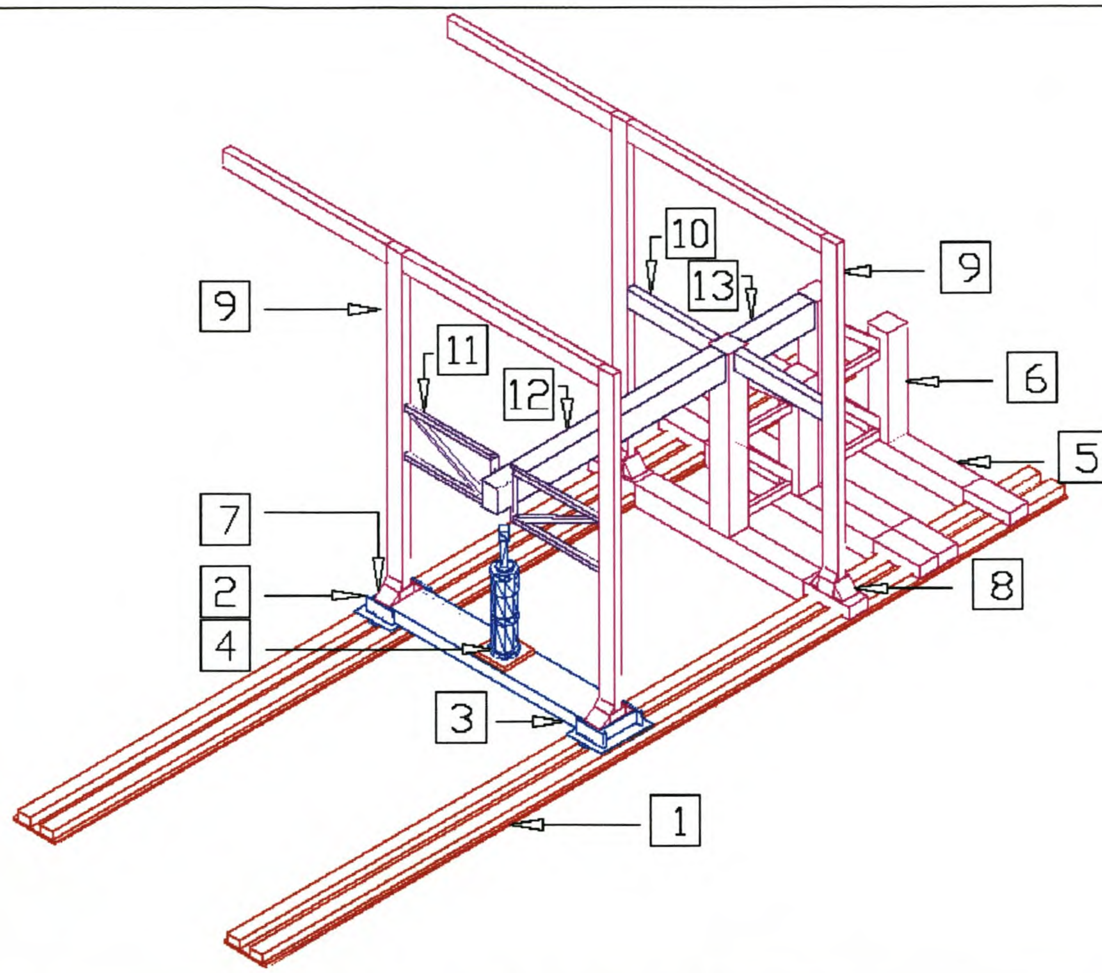
Slabs and wider beams can be tested using two vertical supports to create a wider and stiffer support as illustrated in Figure 4-30.

In this example a slab is tested using the three load bridges to apply a vertical load at quarter spans. No lateral support is provided for the slab, as lateral torsional buckling would not be a failure mechanism.



1.	Tracks	6.	500 kN Servo Hydraulic Actuator
2.	Hinge	7.	Horizontal Support Bridge
3.	62.5 kN Load Bridge	8.	Vertical Support
4.	600 kN Load Bridge	9.	Lateral Support Brace
5.	50 kN Servo Hydraulic Actuator	10.	Slab

Figure 4-30 Test Setup: Example 3 – Testing a Slab



1.	Tracks	8.	Lateral Support Frame / Support Connector
2.	Hinge	9.	Lateral Support Frame
3.	62.5 kN Load Bridge	10.	Lateral Support Brace
4.	50 kN Servo Hydraulic Actuator	11.	Guide Tracks
5.	Horizontal Support Bridge	12.	Beam
6.	Vertical Support	13.	Support Connector
7.	Lateral Support Frame / Load Bridge Connector		

Figure 4-31 Test Setup: Example 4 – Testing a Cantilever

4.7.4 Test Setup: Example 4 – Testing a Cantilever

In Figure 4-31 a cantilever beam is tested using the 62.5 kN load bridge and the 50 kN servo hydraulic actuator to apply a vertical point load at the cantilever end.

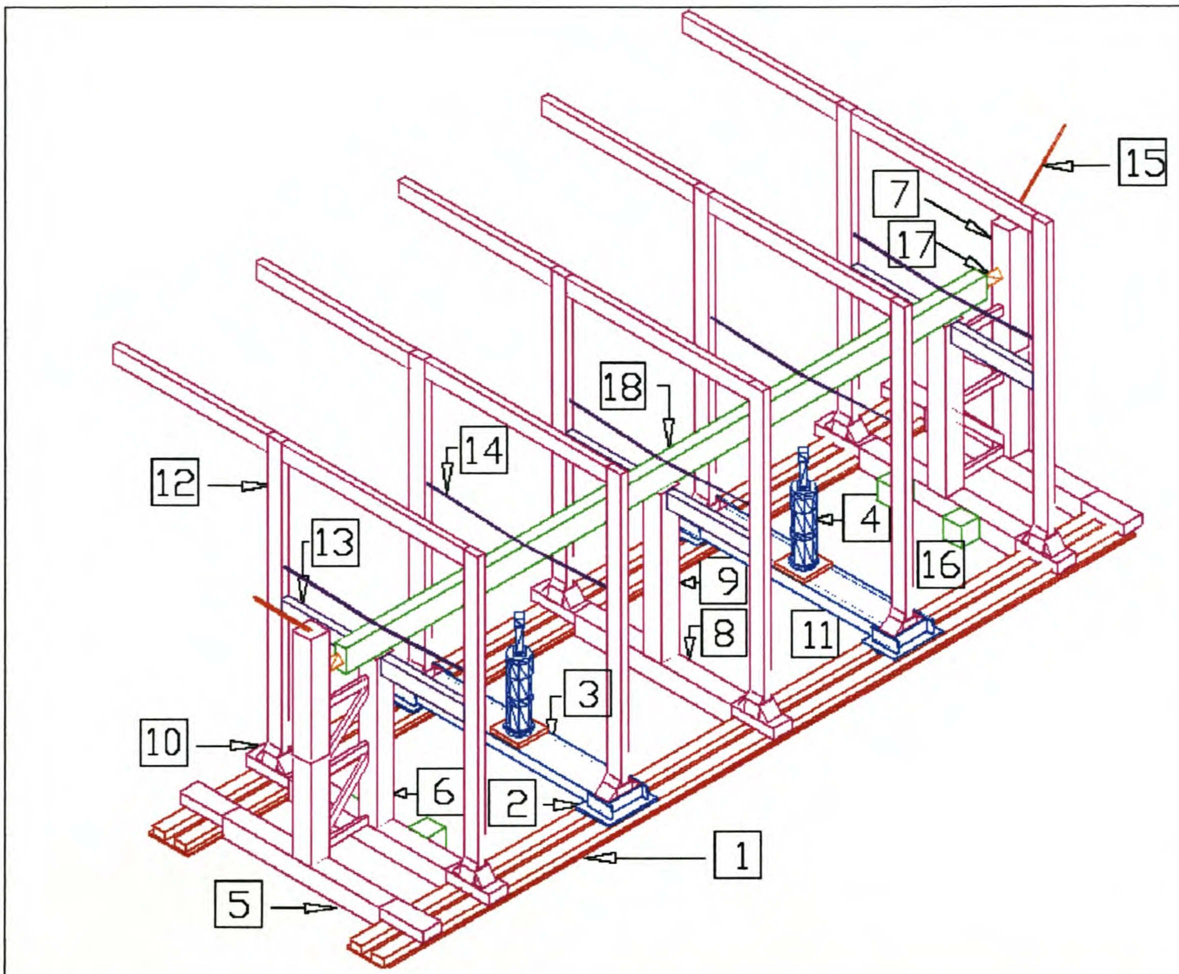
The supports are bolted back to front and connected using a connector of at least the same stiffness as the cantilever beam, as explained in section 4.5. Lateral support is provided at the cantilever end using guide tracks. As the beam would be bolted to the support, the bolted connection together with the stiffness of the lateral support brace and the vertical support would determine the degree of torsional fixity.

4.7.5 Test Setup: Example 5 – Testing a Multi-span Beam/Column

In Figure 4-32 a continuous beam of equal spans is tested under a combination of axial, shear and moment forces.

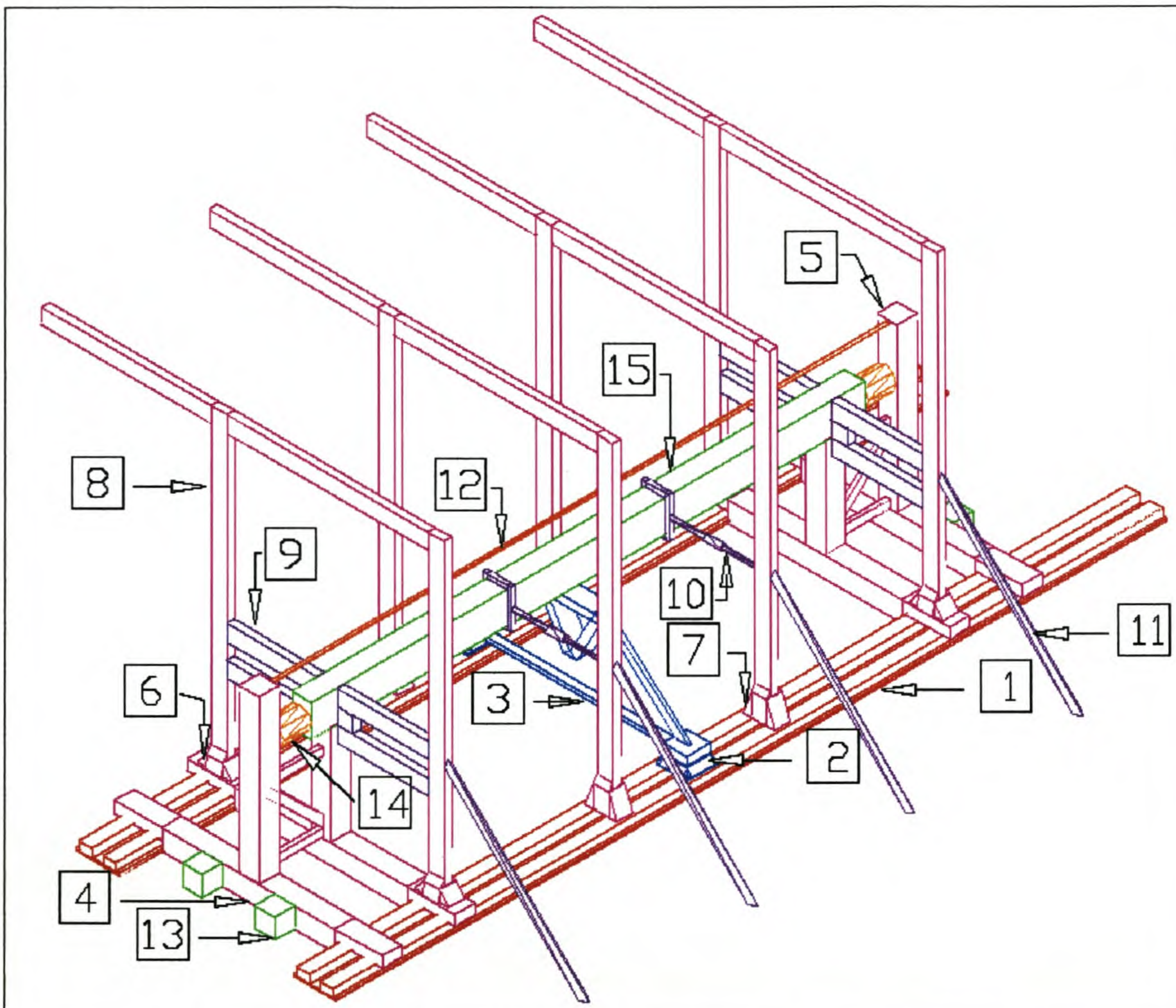
The end supports are extended to create a fixing point for the tension hydraulic actuator and are fixed by using a connecting tie to the first floor and support stops in order to resist the axial forces on the beam. As an alternative to the ties (although not ideal) a compression member can also be used in a similar manner to the tie in Figure 4-33. A single horizontal support bridge and vertical support is used as mod span support.

The 62.5 kN load bridges together with the 50 kN servo hydraulic actuators are used to apply a vertical point load at the centre of each span. Cables are used to supply lateral support at the supports and at mid span.



1. Tracks	10. Lateral Support Frame / Support Connector
2. Hinge	11. Lateral Support Frame / Load Bridge Connector
3. 62.5 kN Load Bridge	12. Lateral Support Frame
4. 50 kN Servo Hydraulic Actuator	13. Lateral Support Brace
5. Horizontal Support Bridge	14. Cables
6. Vertical Support	15. Tie
7. Support Extension	16. Support Stop
8. Single Horizontal Support Bridge	17. Tension Hydraulic Actuator
9. Single Vertical Support	18. Beam

Figure 4-32 Test Setup: Example 5 – Testing a Multi-span Beam/Column



1.	Tracks	9.	Lateral Support (Guide Track)
2.	Gravity Simulator Track Connector	10.	Rod (and Tension Hydraulic Actuator)
3.	Gravity Simulator	11.	Strut
4.	Horizontal Support Bridge	12.	Tie (Cable)
5.	Vertical Support	13.	Support Stop
6.	Lateral Support Frame / Support Connector	14.	Compression Hydraulic Actuator
7.	Lateral Support Frame / Track Connector	15.	Beam
8.	Lateral Support Frame		

Figure 4-33 Test Setup: Example 6 - Testing a Beam/Column under Bi-axial Bending

4.7.6 Test Setup: Example 6 Testing a Beam/Column under Bi-axial Bending

Test example 6, as illustrated in Figure 4-33, displays a beam tested under a combination of axial (vertical and lateral) shear and bi-axial bending moments.

The top brace of the supports are removed to provide for the compression hydraulic actuator. The supports are fixed using the support stops and tying the top of the supports together using a tie member such as a cable.

A vertical point load is applied at mid span using the gravity load simulator. Lateral support is provided at the end supports using guide tracks, while lateral loading and support are applied at third spans using a rod mechanism comprising of a tension Hydraulic Actuator. Struts are used, as explained in section 4.6, to increase the capacity of the lateral support frames.

5 RATIONAL PLANNING AND TESTING USING THE MULTI-PURPOSE BEAM/COLUMN TESTING APPARATUS

5.1 Introduction

It is important for each test to yield a set of meaningful and therefore useful results or data for later use. Without such an outcome, a test can be considered wasted. It is this reason that makes rational planning-and-testing a vital part of each test.

This chapter will take a closer look at the process of rational planning and testing under the following headings:

- Definition of Rational Planning-and-Testing
- Pre-test Planning
- Testing
- Test Evaluation

5.2 Definition of Rational Planning-and-Testing

Rational Planning-and-Testing can be defined as the process of preparing, testing and evaluating the results of a structural test. It will ensure economic and safe testing and provide meaningful test results. This process will link the previous chapters on testing and the MTA, and forms a good summary on testing beams and columns, although it also applies to testing in general.

As can be seen in Figure 5-1 the rational planning process can be divided in three separate phases (or time periods), namely the period before testing, the period during testing and the period after testing.

The period before testing, or pre-test planning period, is required to make decisions on the test sample, the test setup, loading, test data acquisition, the specification, the test value and safety. During testing the test sample and test arrangement need to be evaluated and test data needs to be acquired. After the test, the test data and behaviour of the test specimen should be evaluated in order to make meaningful conclusions. These periods will be discussed in more detail in the following sections.

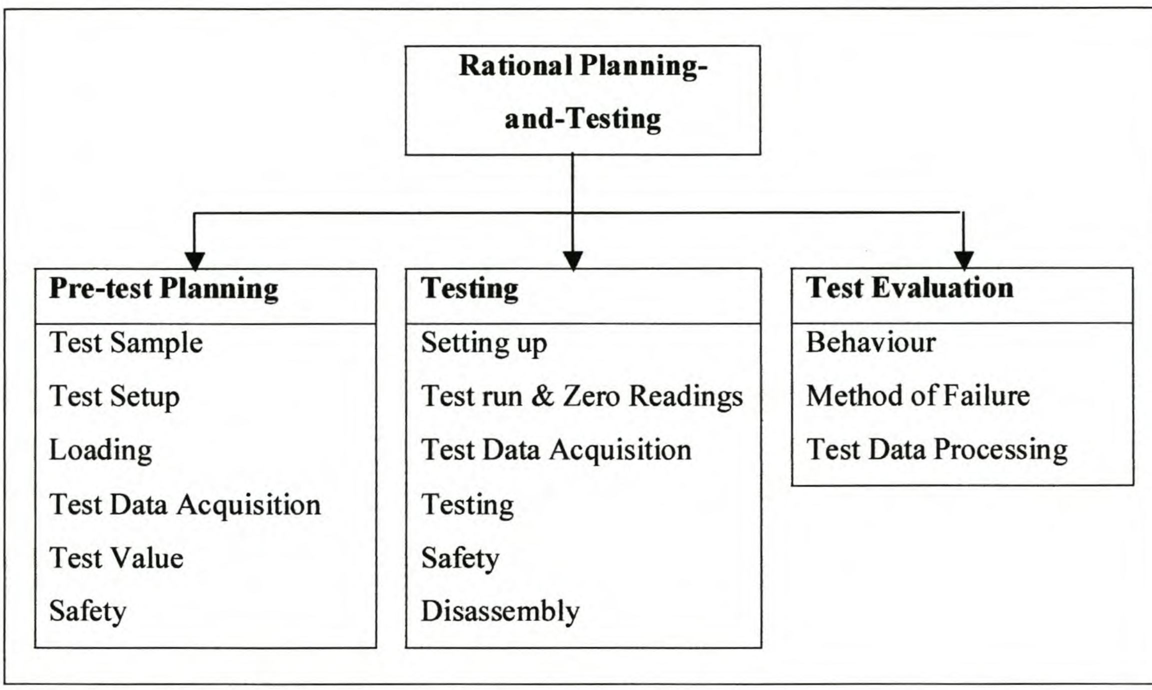


Figure 5-1 Rational Planning-and-Testing Summary

5.3 Pre-Test Planning

Pre-test planning is vital to ensure successful testing and can be seen as a decision making process in which the test sample, the layout, static and kinematic boundary conditions, stability boundary conditions, loading and test data acquisition are varied and the effects thereof compared to the test specification, the test value and safety requirements. This planning process is illustrated in Figure 5-2.

The test sample, the layout, the boundary conditions, the loading and test data acquisition are referred to as test variables, as it can be varied to comply to the test specification, the test value and safety requirements of a test. The test specification, the test value and safety requirements are fixed and are referred to as the test fixities.

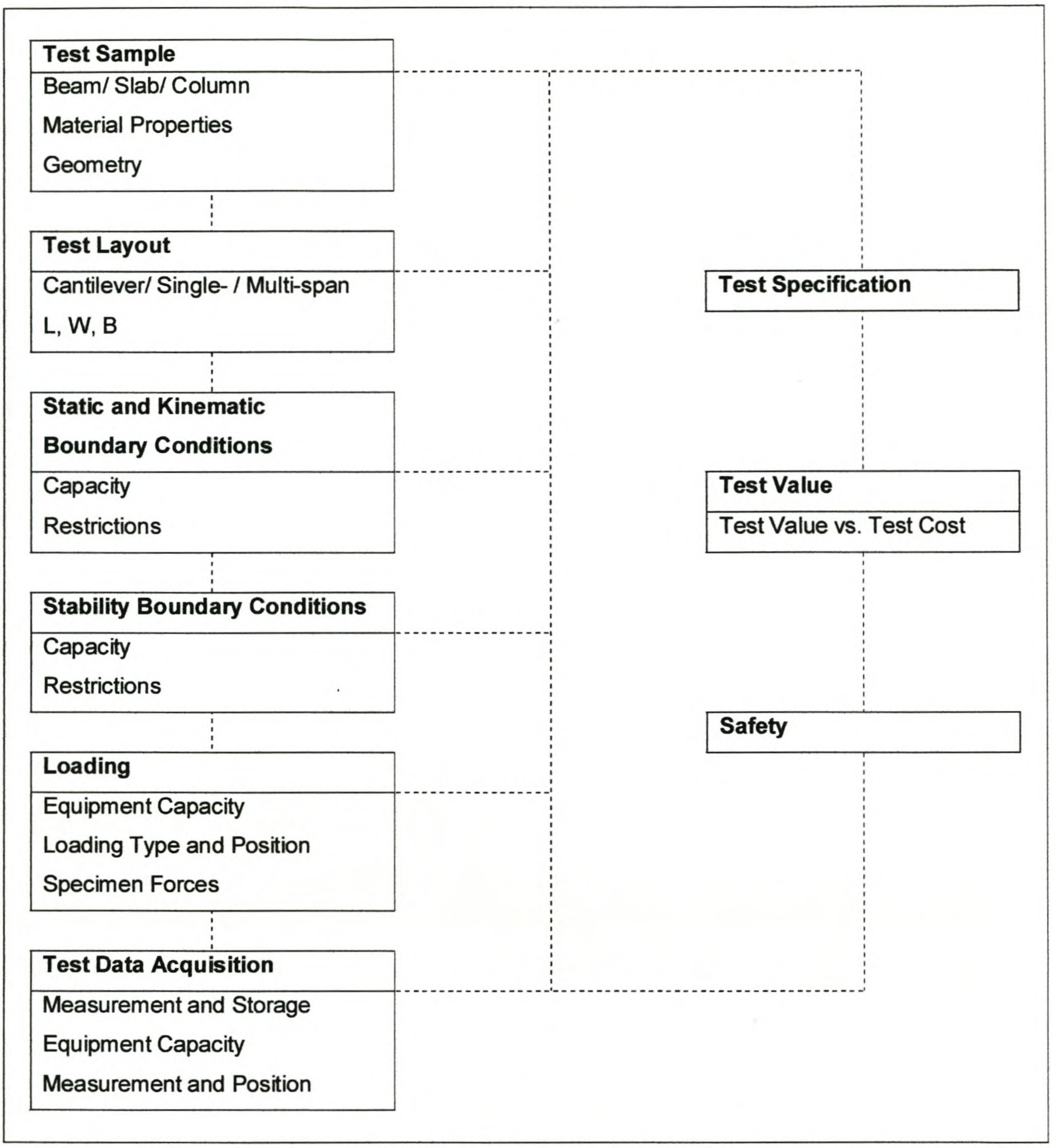


Figure 5-2 Pre-Test Planning Flow Diagram

Pre-test planning is an iterative process in which the influence of each variable on the other variables and the test fixities are determined. The variables must then be adjusted in order to optimise the test.

In this section the different variables and fixities that influence the pre-test planning and decision-making process will be looked at.

5.3.1 Test Sample

During the pre-test planning phase the suitability and preparation of the test sample must be evaluated in relation to the test variables and fixities. This requires the size and loading restrictions the MTA is set up to complies to the test sample. If the test sample is to big for the MTA a scale model can be tested. It is also required to estimate the behaviour of the test sample. The expected behaviour must be re-evaluated in relation to any changes in the test variables in order to see if the test will comply with the test fixities.

The behaviour of the test sample can be estimated from basic structural behaviour and the attributes of the test sample. These attributes include geometrical and material properties and were discussed in detail in chapter 2. Finite elements can also be used to estimate the behaviour of the test sample and are very useful in this regard provided the user understand the concept and limitations of finite element analisys.

The attributes of the selected random test samples must be recorded, which will enable one to relate the test results with regards to the statistical variables of the attributes of the test sample. This will result in the need for fewer tests, as the statistical parameters of the test sample will enable one to draw conclusion on the variability of the test results. As an example: the tolerances in cross sectional properties of an I-Beam will result in a variance in test results. If the tolerances in cross sectional area are varied the influence on the test results can be calculated and verified by doing fewer tests.

5.3.2 Test Layout

The test layout is usually prescribed by the test specification. Other testing variables, such as the specimen size, loading and test data acquisition, can also affect the layout, although usually only on the practicality of the test. Various test layouts and standard test were discussed in chapter 2, and this forms a good background when decisions on the layout is to be made.

5.3.3 Static and Kinematic Boundary Conditions

The End Supports need to satisfy the required static and kinematic boundary conditions, by providing the required restraints or freedom of restraint as required by the test setup. Various standard boundary conditions were discussed in chapter 2, and the use of these boundary conditions using the MTA was illustrated in chapter 4.

The force / displacement / rotation capacity of the end supports should not be exceeded as this will lead not only to unsatisfactory boundary conditions, but also to the failure of the supporting structure. Restraining forces caused by the imperfection of the boundary conditions should also not influence the test results, to ensure that the test comply with the test fixities.

5.3.4 Stability Boundary Conditions

Stability boundary conditions or lateral support, if required by the test specification, will prevent undesirable lateral (stability) failure of the test specimen. The advantages and disadvantages of the various types of lateral supporting mechanisms were discussed in chapter 2 and the user should carefully consider each mechanism as this can influence the cost, the safety and the results of the test.

The force / displacement capacity of the laterally supporting frame and mechanism should not be exceeded, as this will lead to unsatisfactory boundary conditions and cause the failure of the supporting structure. To ensure that the test comply with the test fixities, restraining forces caused by the lateral supporting mechanism should also not influence the test results.

5.3.5 Loading

Loading, and the attributes and types of loading, were discussed in detail in chapter 2. The specimen forces caused due to specific loading types were also discussed. All this, including the available loading equipment and the capacity of the equipment, should be evaluated during the pre-test planning period and compared to the test fixities.

5.3.6 Test Data Acquisition

As discussed in chapter 2, meaningful and therefore useful test results or data is required from each test for later use. This includes visual observations as well as measured readings (manual and electronic) and the storage of such data.

Considering the above during the pre-test planning phase will require summarising the available equipment and the capacity thereof. Critical positions for measurement must be identified from the expected behaviour of the test sample. The test specification may also have prescribed measurement positions. If the test sample is to be tested to failure, it is required to decide on the time of removal of the measuring equipment, in order to prevent damage.

Any changes in the test variables will require the re-evaluation of the acquisition of the test data to ensure that the test complies with the test fixities.

5.3.7 Test Specification

All tests require a specification. This may be prescribed by a national testing standard such as the SABS Standard Methods, or a user defined specification. Chapter 2 provides a good background to standard tests. Using a test specification will enable the user to compare test results as a test specification is a fixity and cannot be varied.

The test specification will usually prescribe the layout, the required boundary conditions (static, kinematic and stability), the loading, the required test data and test sample preparations for a specific test and test sample. The test variables should be adjusted to comply to the test specification.

Where no test specification exists, the user needs to create a specification. The test variables need to comply with this "created" specification. This specification can then be varied in order to optimise the variables.

Tests can also be performed in order to develop a test standard. In such a case, one must vary the standard of each test, comparing the practicality and end results before making a final decision on the required specification.

5.3.8 Test Value

Each test should be assigned a test value, which can be considered to be the value of a successful test. This test value is a hypothetical value, which will express the research and educational value of a successful test as a financial value. In the case where testing is required for product development or quality control, it is easier to assign such a financial value to a successful test as the financial gain due to a product of high quality or a new product is known.

At various stages during the rational planning process, the Test Value must be compared to the test cost. The test cost is not only a function of the financial cost of the test, but also of time and other available resources and is expressed in terms of a financial value. If the test value is greater than the test cost, testing or an additional test can be justified. If not, the test cannot be justified and should seriously be reconsidered (e.g. the fifth test of an identical test sample tested to failure under the same test arrangement as the previous four).

5.3.9 Safety

Safety forms an important part of testing, not only because of cost related to injury, damage or loss, but because of the legal implications (Law on Career Safety, Law 85 of 1993). It is therefore important to identify the risk and danger of each test and to do everything within reason to minimize this danger and risk. Here follows a few safety regulations to ensure safe testing (For a full set of safety regulations and the view of the University of Stellenbosch to the Law on Career Safety, refer to *The Safety User's Manual for the Department of Civil Engineering* [20]):

General Safety Regulations:

- Nobody is allowed to work in a laboratory or workshop on his/her own. Another person should be at least within shouting distance. This applies especially after hours.
- Nobody may use any crane machine or apparatus without proper training. Training means that a person was informed about the working of and the risk concerning the equipment in question and that he has signed a register confirming the above.
- Students must display their names, as well as the name of the relevant lecturer, at the test set-up. This will also prevent equipment being removed or tampered with.
- It is compulsory to wear ear protection if the noise levels are high.
- It is compulsory to wear eye protection when working with a grinding/cutting machine.
- No loose hair or clothing may be worn when working with any machinery.
- No sandals or open shoes may be worn in the workshop and laboratories.
- A safety hat must be worn if work is being done overhead.
- Only qualified persons may modify electrical equipment.
- Keep your working environment neat and clean to prevent accidents.

Safety Regulations Using MTA:

- Make sure that all equipment is in working order before using it.
- Do not exceed the capacity of the testing or measuring equipment, as this will damage the equipment beyond repair.
- Stand at a safe distance and wear the necessary protective garments during testing.
- Make sure that all connections on the MTA are as required for the test. Where movement is required, make sure it can be achieved.
- The tests set-up must include emergency switches to stop the test if required.
- Ensure that the failure of the sample will not cause damage or injury. Remove measurement equipment before failure and keep a save distance at failure.

5.4 Testing

Testing in terms of the rational planning refers to all laboratory work required before, during and after testing. As can be seen in Figure 5-2, this would include the setting up of the test sample in the MTA with the required boundary and loading conditions, a test run, taking zero readings, testing the specimen, test data acquisition, safety during testing and the cleaning up afterwards.

The selected test sample must be prepared and set up in the MTA so that the test variables comply with the fixities as required and determined in the pre-test planning process. The laboratory time required for setting up will be drastically reduced pending the detail of the pre-test planning. The attributes of the test sample (geometric, and especially material properties) also need to be verified. This will prevent testing a false sample that will lead to unexplained test results.

Before commencing with the test, the test set-up and equipment must be tested to ensure a successful test. This is done best by a test run or trail load. The test sample is loaded and the load released to ensure that the test set-up and all measurement and loading equipment and safety precautions are in order. The loading during the test run could be as little as 5 % of the total load [21] but should not exceed the elastic limit of the test piece to ensure that the test run will not influence the test result. The test run will enable the user to re-evaluate the test setup and make minor adjustments to the setup if required prior to testing.

Once the test run is completed successfully and no more minor adjustments are required, zero readings can be taken and the test can commence. The behaviour of the test sample, the test setup, the loading and data acquisition equipment will have to be monitored during the test to ensure a successful test. Any deviation to the expected behaviour should be evaluated to ensure that it is not caused by imperfections in the test setup. Measurement and loading equipment are constantly to be monitored to ensure the correct working thereof during the test.

Manual adjustments and the removal of measurement equipment (if required) must be done with care to ensure safety and accurate test data. It is also important to maintain the highest safety standards and monitor all safety precautions during testing to prevent injury and loss.

Upon completion of the test, the test must be evaluated as described in the following section. If evaluated as successful, the test setup can be disassembled and cleaned to allow for the next test.

5.5 Test Evaluation

Before a test can be deemed successful it must first be evaluated. In this evaluation process the behaviour of the test sample needs to be compared to the expected behaviour. One should verify that any deviations to the expected behaviour were not caused by an inaccurate test sample or test set up. Similarly, an inaccurate setup should not cause the test sample to behave in the expected manner. For these reasons it is important to monitor the test sample and test setup during the test as discussed in the previous section.

The expected behaviour, as it is only the expected behaviour, will not always be assumed correctly, and the user needs to keep this in mind when the test is evaluated. This will require the user to re-evaluate the expected behaviour by interpreting the test behaviour. The user might require retesting the test sample, or the preparation and testing of another sample to verify the behaviour of the test sample before he will be able to adjust his expected behaviour.

The collected test data must also be evaluated to ensure the correct recording of the test data. A preliminary plot of deflection or strain versus the applied load would give a good indication of this. In the case where the set sample is tested to failure, the method of failure must correlate with the collected test data. Notes during testing on the behaviour of the test sample would also be useful to evaluate the authenticity of the test data.

Note that this process will not require the test data to be interpreted, but only the verification of a correct test sample, correct test setup an the correct recording of the test data. Such a test yields meaningful and therefore useful results or data for later use and can be deemed to be successful.

6 EVALUATION OF THE MULTI-PURPOSE BEAM/COLUMN TESTING APPARATUS

6.1 Introduction

To date the MTA has been used for the testing of various structural elements, including the simulation of the wheel loads of an overhead crane on a rail track, vertical and lateral loading on a crane beam and the deflection of trusses with welded and bolted connections.

As an illustration and evaluation of the use of the MTA and the Rational Planning Process, the process followed to test and the testing of a welded truss will be discussed in more detail.

6.2 Deflection Evaluation of Steel Trusses

Steel trusses were tested as part of under-graduate research [22] to compare the theoretical deflections of the steel trusses to the experimental values. In this section we will take a closer look at the objective of the research, the pre-test planning, the testing and the test evaluation of this experimental work (Refer to appendix B for more detail on the testing).

6.2.1 Objectives of Research

The objective of the research was to compare the theoretical deflections of a steel truss to experimental values and to draw conclusions on the findings. Although the research required the testing of two similar steel trusses, one with welded and one with bolted connections, only the testing of the welded truss will be used to illustrate the use of the MTA.

The trusses were designed for two point loads of 35 kN each at third span. The deflection of the truss at mid span was analytically calculated for various point loads and was compared to the experimental readings.

6.2.2 Pre-test Planning

The iterative process of the pre-test planning phase is illustrated in Figure 6-1. The two test samples (or trusses) were made of standard angle sections (grade 300 WA steel), one with bolted and one with welded connections, and were designed to fall within the size and loading limits of the MTA. A typical truss is illustrated in Figure 6-2. These trusses were set up as simply supported trusses as to comply with the test specification.

No manual adjustments to the lateral supporting system were desired during the tests, hence the decision to use linear guide tracks at the supports and at third spans to provide lateral support as they will allow large deflections with no restraining forces. The capacity of all supports and restraints were checked and verified to exceed the required values of the test.

Two gravity load simulators, using 20 ton Enerpack hydraulic loading actuator, were used to apply a stabilising linear increasing point load. Strain gauges, load cells and LVDTs were used to collect test data digitally as indicated in Figure 6-2. The theoretical test setup is illustrated in Figure 6-2 and Figure 6-3.

The theoretical deflection of the truss at various load increments up to the design load was calculated beforehand to compare with the values during the test. This gave a good indication of the expected behaviour of the test samples. It was expected for the welded truss to be stiffer than the bolted truss, as slip of the bolted connections would be expected.

Test Sample

Sample 1: Welded Steel Truss

Sample 2: Bolted Steel Truss

Material: Grade 300 WA Steel

Geometry: Indicated in Figure 6-2 and Figure 6-3

Test Layout

Single-span, simply supported

L = 7 200 mm B = 110 mm

H = 1200 mm

Static and Kinematic Boundary Conditions

$C_r >> C_u$ = 35 kN

Restrictions: simply supported

Stability Boundary Conditions

$C_r >> C_u$ = 0,565 kN

Vertical linear guide used, no restraints or adjustments required during test

Loading

Equipment: 2No. Gravity load simulators (20 ton)

Loading: Stabilising Point load at third span

Forces: calculated using Prokon software

Test Data Acquisition

Measurement Equipment:

Strain gauges - as indicated in Figure 6-2

Load cells - at loading points (third spans)

LVDT- measure deflection at mid span

Equipment Capacity >> Test Requirements

Measurement and Position

Test Specification

Simply supported truss with point loads at third span.

Deflection required at mid span.

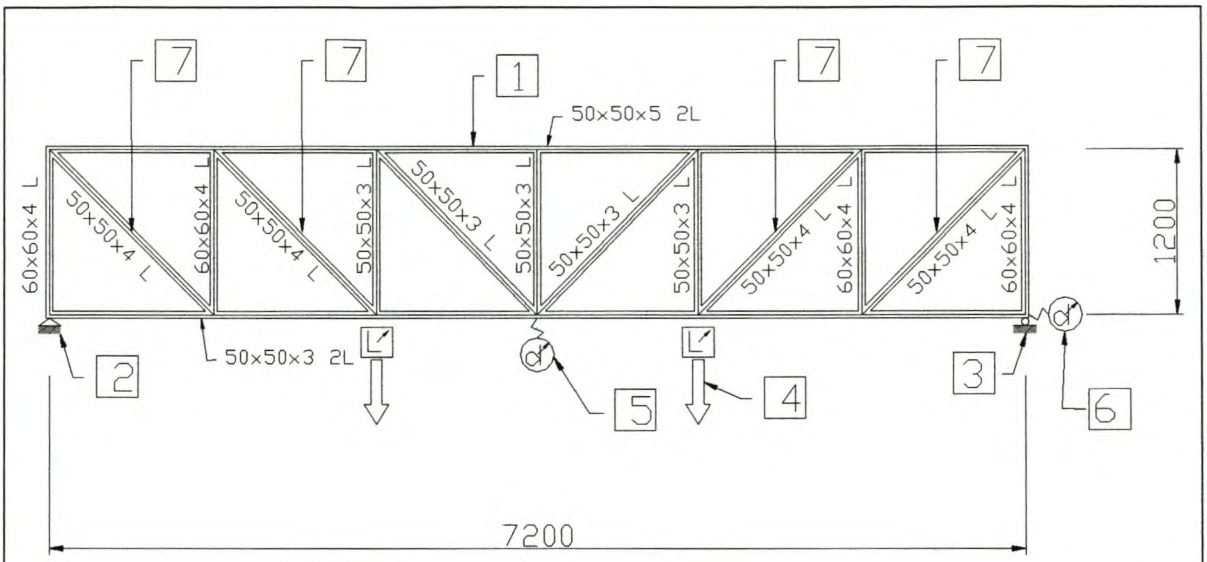
Test Value

Test Value >> Test Cost

Safety

LVDT removed at P_u

Figure 6-1 Pre-Test Planning Flow Diagram



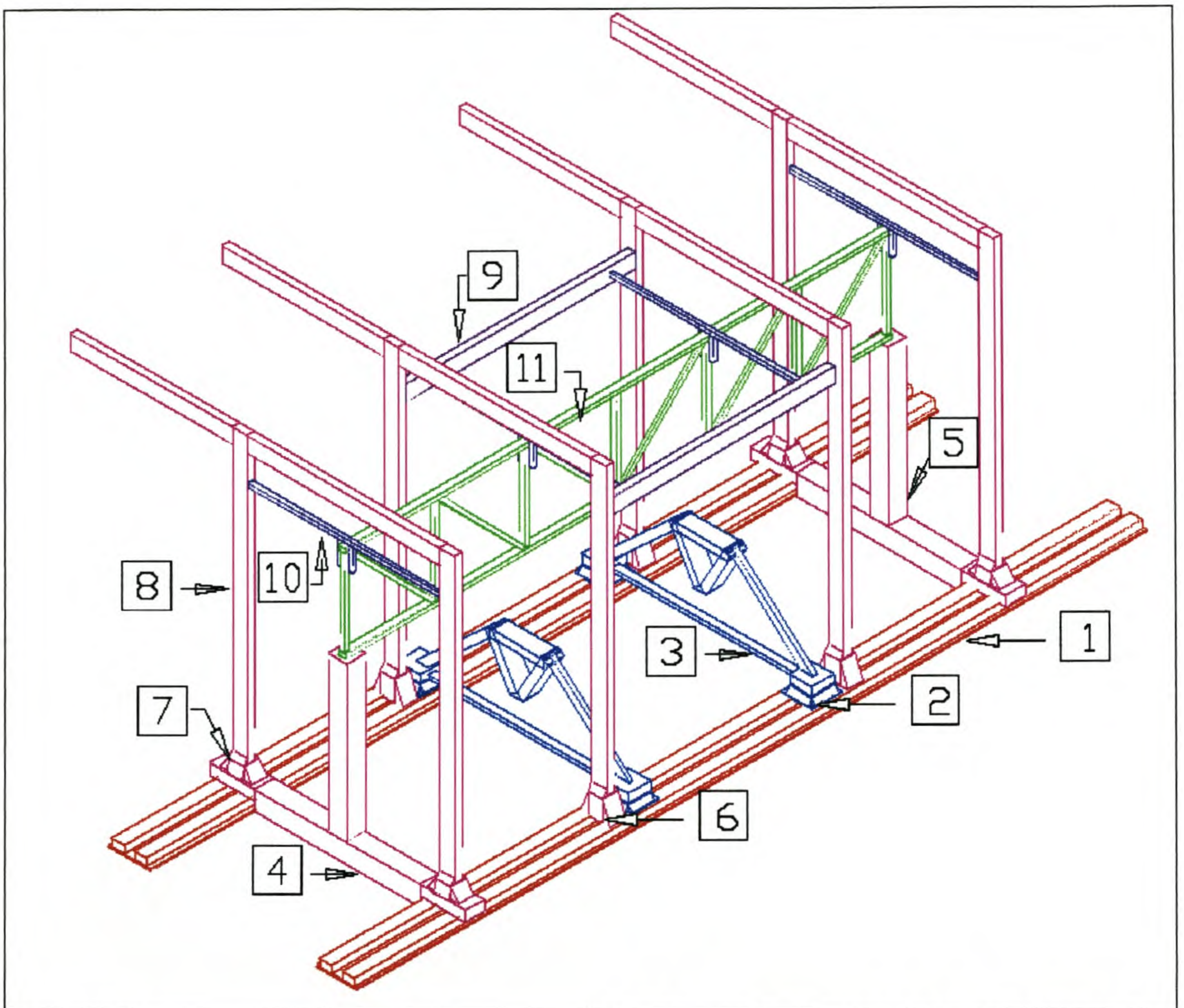
1. Truss	5. LVDT (Displacement Measurement)
2. Pinned Support	6. LVDT (Displacement Measurement)
3. Roller Support	7. Strain Gauges
4. Load Cell and Loading Actuator	

Figure 6-2 Theoretical Test Setup

The test value was not only related to the value of the pre-graduate research, but the bolted truss was also built as a display experiment and used in an engineering open day display.

The test cost can be related to the cost of the trusses. Each truss, weighting around 146kg, costs about R1700.00 (working on current steel manufacture and erection rates, and ignoring possible salvage values). As the test value exceeds the test cost, the tests can be justified.

The test setup and testing were done with the safety regulations and precautions (as discussed in the previous chapter) in mind. Only the welded truss was to be tested to failure, and the LVDTs had to be removed at the design load.



1. Tracks	7. Lateral Support Frame / Support Connector
2. Gravity Simulator Track Connector	8. Lateral Support Frame
3. Gravity Simulator	9. Lateral Support Frame Brace
4. Horizontal Support Bridge	10. Lateral Support Mechanism: Guide Tracks
5. Vertical Support	11. Truss
6. Lateral Support Frame / Track Connector	

Figure 6-3 Test Setup for Deflection Evaluation of Steel Truss

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6.2.3 Testing

As discussed in the previous chapter, testing refers to all laboratory work. In the case of testing the trusses it included the preparation of the test samples, setting up for testing, checking all measurement equipment, ensuring safety precautions are in place, a test run, minor adjustments and testing.

As the experiment was aimed at steel trusses in practice, the section sizes of all steel members and the accuracy of the manufactured truss were assumed to be within the allowable tolerances as stipulated by SABS 1200 [23] and SABS 0162 [2].

Test Sample 1, or rather the welded truss, did not require any special preparation. The truss was set up and tested up to the design load, adhering to the testing procedure as described in the previous cbapter. The loads were then gradually released so that any permanent deflections could be measured. The truss was then retested up to failure, with the LVDT being removed at the design load (the test results for this truss will be discussed in the following section).

The preparation of Test Sample 2, or rather the bolted truss, required all bolts to be tightened to the same tension. As these bolts were not friction grip bolts, the tension value in this research was not of importance. The truss was then set up and tested up to the design load. The loads were then gradually released so that any permanent deflection caused by the slipping of the bolted connections could be measured. The truss was then again tested to the design load and the load released to measure if slip still occurs. The truss was not tested to failure as to allow future tests with friction grip bolts and to use as a display exhibit.

After the completion of the tests, the test data was verified and the test area cleaned up, so as to complete the test.

6.2.4 Test Evaluation

As the research relating to the deflection of trusses and interpretation of the test data falls outside the scope of this thesis, only a brief summary of the test results of the welded truss will be discussed to illustrate the use of the MTA and the Rational Planning concept.

The test data of the welded truss was imported into a spreadsheet, and calibrated. The theoretical and experimental displacements were then plotted against the loads in order to compare them, as illustrated in **Figure 6-4**.

The experimental values correlate closely to the theoretical values, indicating a correct assumption of the expected behaviour of the truss and a successful test. The test data of the welded truss can now be used to compare to the values of the bolted truss and to draw conclusions on the deflection and deflection calculation of trusses.

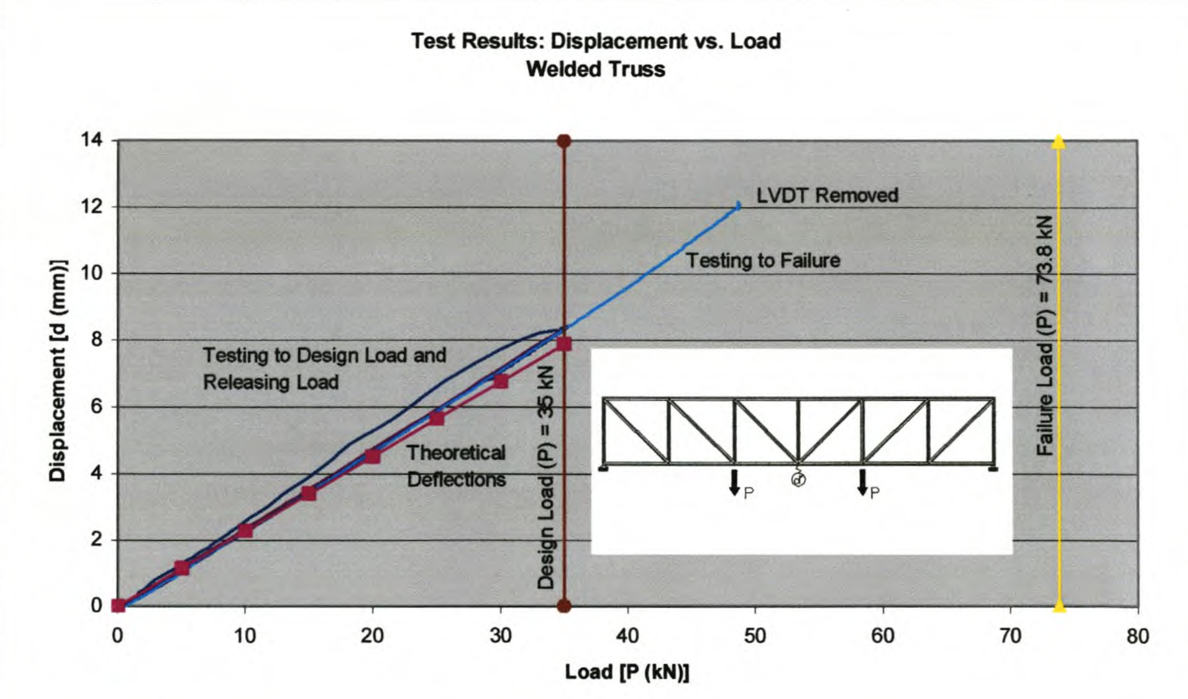

Figure 6-4 Displacement versus Load: Test Sample 1

6.3 Evaluation of the MTA

As illustrated in this chapter the MTA allows for flexibility in testing as a variety of standard and unique tests have already been performed using the MTA as basis for the test setup.

The MTA also allows for fast effective testing in line with the rational planning-and-testing concept, making testing more cost effective, and also allows faster advances in research.

7 SYNOPSIS

7.1 Overview of the Thesis

In this thesis a multi-purpose beam/column testing apparatus (MTA) has been developed following a literature study on laboratory tests of structural elements.

The objective of the MTA were to ensure successful testing and to maximize the potential of the main test floor of the Structures Laboratory as the fixing points of the test floor is spaced at 920 mm cross-centres, which limited the testing of beams.

The apparatus, adhering to all testing requirements, makes provision for testing beams and columns of various sizes, static and kinematic boundary conditions, and variable load combinations. These test variables can be adjusted with minimum effort in order to deduce the cost of setting up as the MTA consists of different components. These different components also increase the flexibility of the apparatus. The flexibility of the MTA was illustrated by using three-dimensional sketches created by cross-referenced drawings.

A rational planning procedure to assist in the pre-test planning phase was developed. This planning process ensures meaningful test results and is illustrated together with the use of the MTA in testing a simply supported truss.

A literature review provides the reader with a good understanding to structural tests, which together with the rational planning process will ensure successful testing.

7.2 Future Research, Development and Improvements of the MTA

The MTA makes provision for testing beams under various static and kinematic boundary conditions. As part of future research, the use of various techniques to provide static and kinematics boundary conditions and the effectiveness of each technique on the test results can be evaluated. New and possibly more effective techniques can be researched and developed.

Due to the flexibility of the MTA an additional overhead frame for the MTA can be developed to apply a point load using the servo hydraulic actuators. Ideally this frame should allow for the overhead and horizontal application of a point load in a similar manner to the load bridges.

7.3 Conclusions

Not only did the MTA perform as planned in the test example, but to date it was also used, with great success, in testing other structural elements including testing a truss, a crane wheel on a crane track, an overhead crane beam and a portal frame.

The use of the rational planning process, together with three-dimensional modelling, was illustrated. This ensures an effective pre-test planning process resulting in meaningful test results.

Although the flexibility of the MTA is not displayed in the test example, future tests and research will be enhanced and not limited due to the flexibility of the MTA.

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APPENDIX A

This appendix contains a full drawing register of all drawings, the production drawings and an example of the use of the three-dimensional cross-referenced CAD drawings.

A.1. Drawing Register and Production Drawings

Drawing Code:

01-01/1

→ Sheet no.

→ No. off detail drawing

→ 3D 3-dimensional drawings

→ WS Workshop drawings

→ Item no. Item

Item no.	Item
01	Tracks
02	Hinge, Pins, Bearings
03	Loading Bridges
04	Supports
05	Lateral Supports

□ Welded Part

○ Bolted Component

Figure A.1 Explanation of Drawings and Drawing Numbers

A.1.1. List of Three Dimensional Workshop Drawings

Drawing Number	Drawing Name/Description	Latest Revision
01-3D-01	Track	12/02/2000
02-3D-01	Hinge	12/02/2000
02-3D-02	Hinge Fixing Bracket	12/02/2000
03-3D-01	500 kN Bridge	12/02/2000
03-3D-02	50 kN Bridge	12/02/2000
03-3D-03	Gravity Load Simulator	05/01/2001
03-3D-04	Type A Connector	05/01/2001
04-3D-01	Support	12/02/2001
05-3D-01	Lateral Support	12/02/2001
05-3D-02	Connector: Type B	12/02/2001
05-3D-03	Connector: Type C	12/02/2001
05-3D-04	Connector: Type D	12/02/2001

Note: These drawings were created using three-dimensional geometric entities available in AUTOCAD 14 and therefore do not reflect the full detail of the component.

A.1.2 List of Detail Drawings

Drawing No.	Drawing Name/Description	Latest Revision
01-01/1	Tracks: Front/Top View	02/08/2000
01-01/2	Tracks: Section BB	02/02/2000
02-01/1	Hinge: Front/Top/Left View	25/10/1999
02-01/2	Hinge: Detail A (Welding)	25/10/1999
02-02/1	Hinge: Pins & Bushes	05/01/2000
02-03/1	Hinge: Fixing Bracket	25/10/1999
03-01/1	500kN Load Bridge	02/09/2000
03-01/2	500kN Bridge: Sections AA/ BB	25/01/2000
03-01/3	500kN Bridge: Welding Detail	25/01/2000
03-02/1	50kN Load Bridge	02/09/2000
03-02/2	50kN Bridge: Sections AA/BB	25/01/2000
03-02/3	50kN Bridge: Welding Detail	25/01/2000
03-03/1	Gravity Load Simulator	03/03/2001
03-03/2	Connector: Type A	25/10/1999
04-01/1	Vertical Support	25/10/1999
04-01/2	Vertical Support: Welding Detail	25/10/1999
04-02/1	Support Bridge	25/10/1999
04-02/2	Support Bridge: Welding Detail	25/10/1999
05-01/1	Lateral Support Frame	25/10/1999
05-01/1	Lateral Support Frame: Welding	25/10/1999
05-02/1	Connector: Type B	02/01/2001
05-03/1	Connector: Type C	02/01/2001
05-04/1	Connector: Type D	25/10/1999

A.1.3 List of Workshop Drawings

Drawing Number	Latest Revision	Drawing Name/ Item Mark /Description/
01-WS-1	2/12/2000	Track
		01 - 01 $\boxed{1}$ Angles
		01 - 01 $\boxed{2}$ Base Plate
01-WS-2	26/01/2000	Track
		01 - 01 $\boxed{3}$ Web Stiffener
		01 - 01 $\boxed{4}$ Web Stiffener
02-WS-1	26/10/1999	Hinge
		02 - 01 $\boxed{1}$ Web Plates
		02 - 01 $\boxed{2}$ Base Plate
02-WS-2	11/01/2000	Hinge
		02 - 02 $\boxed{1}$ Pin
		02 - 02 $\boxed{2}$ P10 Bushes
02-WS-3	26/10/1999	Fixing Bracket
		02 - 03 $\boxed{1}$ Web
		02 - 03 $\boxed{2}$ Flange
02-WS-4	11/01/2000	Hinge
		02 - 02 $\boxed{3}$ Pin

03-WS-1	26/01/2000	500kN Bridge				
		03	-	01	1	Flange Plate
		03	-	01	2	Flange Plate
		03	-	01	5	Flange Plate
03-WS-2	26/01/2000	500kN Bridge				
		03	-	01	3	Web Plate
		03	-	01	4	Web Plate
		03	-	01	6	Web Plate
03-WS-3	27/01/2000	500kN Bridge				
		03	-	01	7	Flange Plate
		03	-	01	8	Flange Plate
03-WS-4	27/01/2000	500kN Bridge				
		03	-	01	9	Hinge Plate
		03	-	01	9x	Hinge Plate
03-WS-5	27/01/2000	500kN Bridge				
		03	-	01	10	Hinge Plate
		03	-	01	10x	Hinge Plate
03-WS-6	27/01/2000	500kN Bridge				
		03	-	01	11	Web Stiffener
		03	-	01	12	Web Stiffener
		03	-	01	13	Web Stiffener
03-WS-7	27/01/2000	50kN Bridge				
		03	-	02	1	Flange Plate
		03	-	02	2	Flange Plate
		03	-	02	5	Flange Plate
03-WS-8	28/01/2000	50kN Bridge				
		03	-	02	3	Web Plate
		03	-	02	4	Web Plate

03-WS-9	03/02/2000	50kN Bridge
		03 - 02 9 Hinge Plate
		03 - 02 9x Hinge Plate
03-WS-10	26/10/1999	50kN Bridge
		03 - 01 10 Hinge Plate
		03 - 01 10x Hinge Plate
03-WS-11	26/10/1999	Connector A
		03 - 03 1 Base Plate
		03 - 03 2 Base Plate
03-WS-12	26/10/1999	Connector A
		03 - 03 4 Web Plate
		03 - 03 5 Web Plate
		03 - 03 6 Web Plate
04-WS-1	05/10/2000	Vertical Support
		04 - 01 1 Support Column
04-WS-2	05/10/2000	Vertical Support
		04 - 01 2 Support Column
04-WS-3	20/10/2002	Vertical Support
		04 - 01 3 Support Brace
		04 - 01 4 Support Brace
		04 - 01 5 Support Brace
04-WS-4	26/10/1999	Vertical Support
		04 - 01 6 Support Cap Plate
		04 - 01 7 Support Base Plate
04-WS-5	20/10/2002	Vertical Support
		04 - 01 8 Brace End Plate

04-WS-6	05/10/2002	Support Bridge			
		04 - 02	1	Support Beam	
04-WS-7	26/10/1999	Support Bridge			
		04 - 02	2	Support Plate	
		04 - 02	3	Web Stiffener	
04-WS-8	26/10/1999	Support Bridge			
		04 - 02	4	Web Stiffener	
		04 - 02	5	Web Stiffener	
05-WS-1	26/10/1999	Lateral Frame			
		05 - 01	1	Lateral Frame: Column	
		05 - 01	2	Lateral Frame: Beam	
05-WS-2	26/10/1999	Lateral Frame			
		05 - 01	3	Lateral Frame: Beam	
		05 - 01	8	Stiffener	
05-WS-3	26/10/1999	Lateral Frame			
		05 - 01	4	Base Plate	
		05 - 01	5	End Plate	
05-WS-4	26/10/1999	Lateral Frame			
		05 - 01	6	End Plate	
		05 - 01	7	End Plate	
05-WS-5	26/10/1999	Connector: Type B			
		05 - 02	1	Base Plate	
		05 - 02	2	Base Plate	
05-WS-6	26/10/1999	Connector: Type B			
		05 - 02	3	Web Plate	
		05 - 02	4	Web Plate	
		05 - 02	5	Web Plate	

05-WS-7	26/10/1999	Connector: Type C				
		05	-	03	1	Base Plate
		05	-	03	2	Base Plate
05-WS-8	26/10/1999	Connector: Type C				
		05	-	03	3	Web Plate
		05	-	03	4	Web Plate
		05	-	03	5	Web Plate
05-WS-9	26/10/1999	Connector: Type D				
		05	-	04	1	Base Plate
		05	-	04	2	Base Plate
05-WS-10	26/10/1999	Connector: Type D				
		05	-	04	3	Web Plate
		05	-	04	4	Web Plate
		05	-	04	5	Web Plate

A.1.4 Three-Dimensional Cross-Referenced CAD Drawings:

Each component of the MTA is modelled from of basic geometric entities using AUTOCAD 14. These components are cross-referenced to a master three-dimensional drawing with the test floor layout as basis. Three-dimensional modelling test-setups can be checked in the pre-test planning phase, and display models created with AUTOCAD 14. CAD features such as render, hidden line and different viewpoints make it ideal for modelling visual display setups and it was used to create test examples in chapter 4.

In Figure A.2 a test setup is created using the three-dimensional cross-referenced CAD drawings and basic AUTOCAD 14 functions such as move and copy. Drawing layers can be turned on and off, and the shade, hidden line and viewpoint functions used to create display setups as in Figure A.3 and Figure A.4.

As all the components of the MTA are to scale, it is possible to check for any otherwise unforeseen problems that might occur with the test setup.

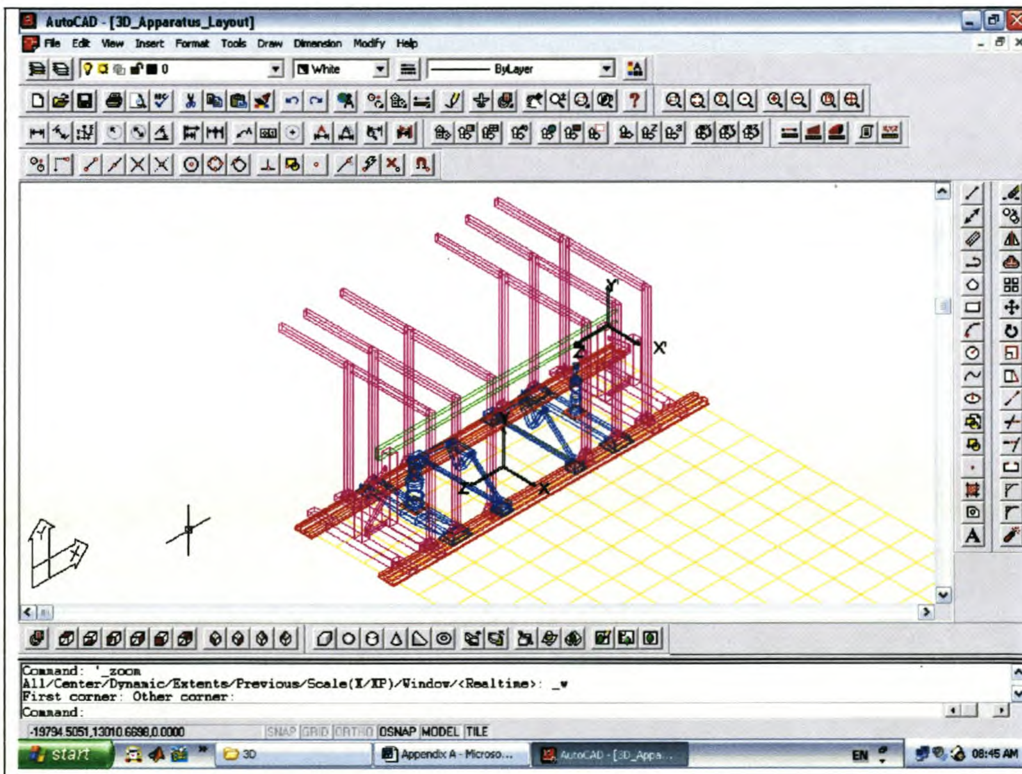


Figure A.2 A Test Setup is created using AUTOCAD 14

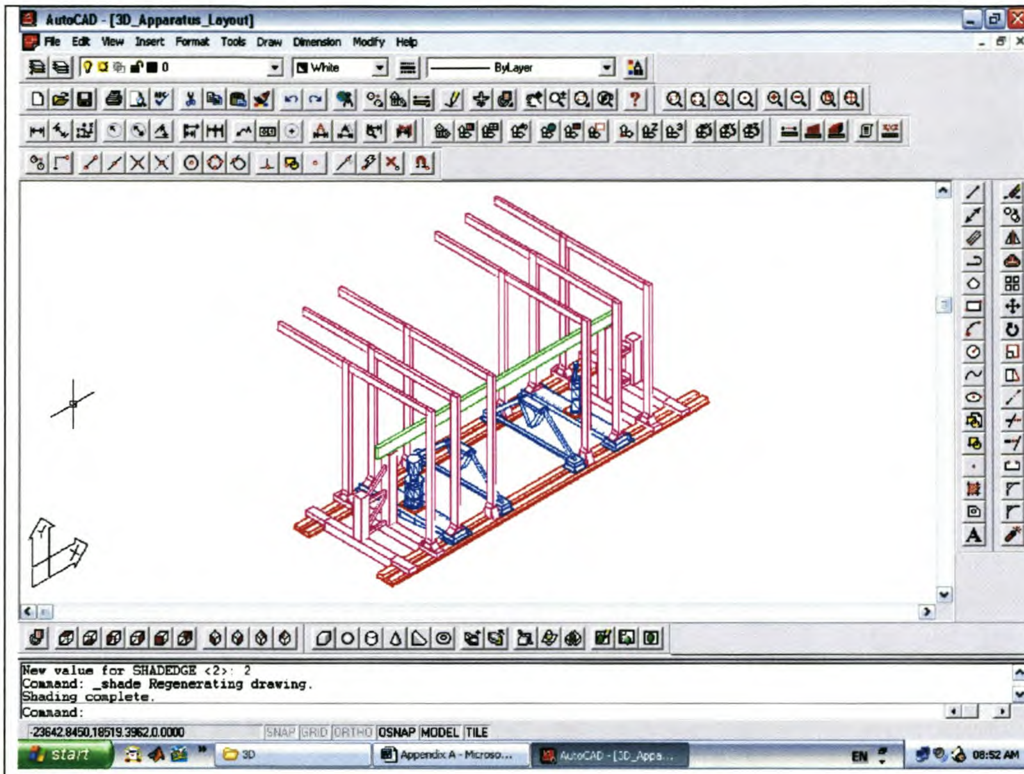


Figure A.3 The Test Setup using the Hidden Line Function in AUTOCAD 14

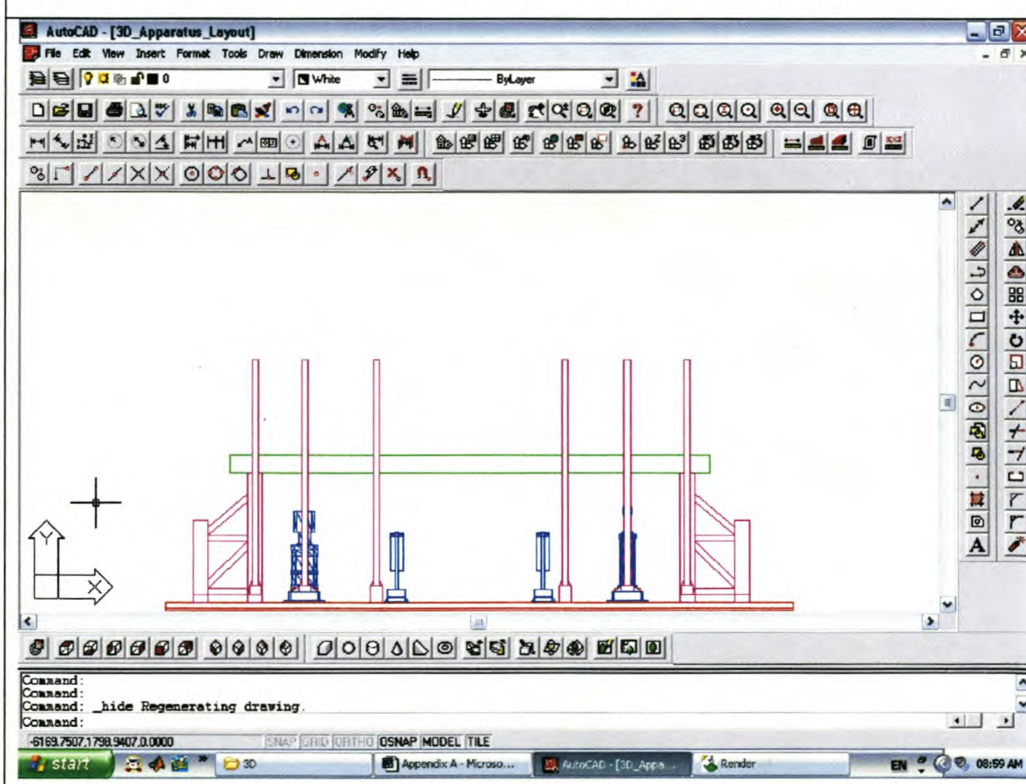
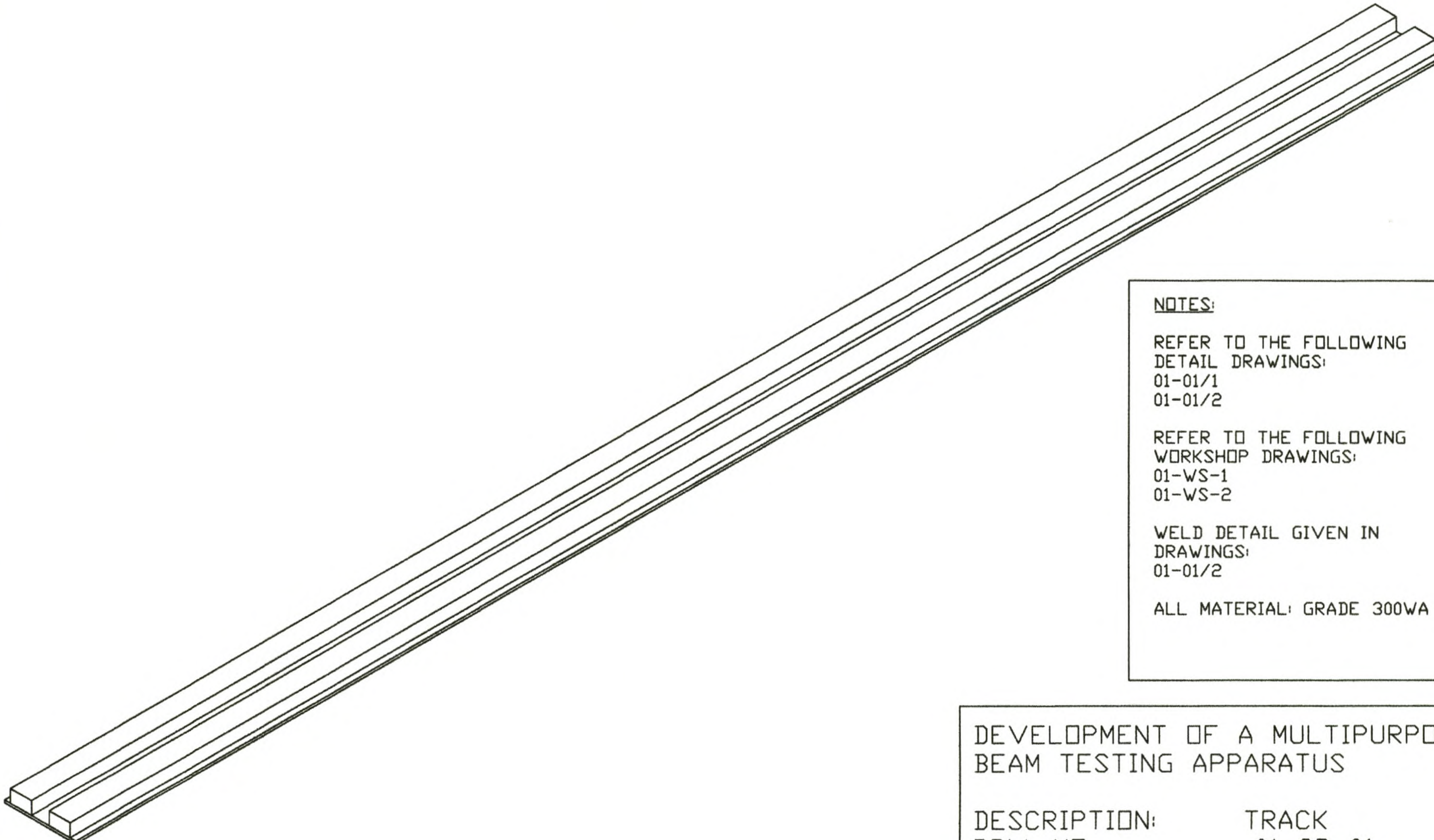


Figure A.4 The Test Setup view from the side using AUTOCAD 14



TRACK

NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
01-01/1
01-01/2

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
01-WS-1
01-WS-2

WELD DETAIL GIVEN IN DRAWINGS:
01-01/2

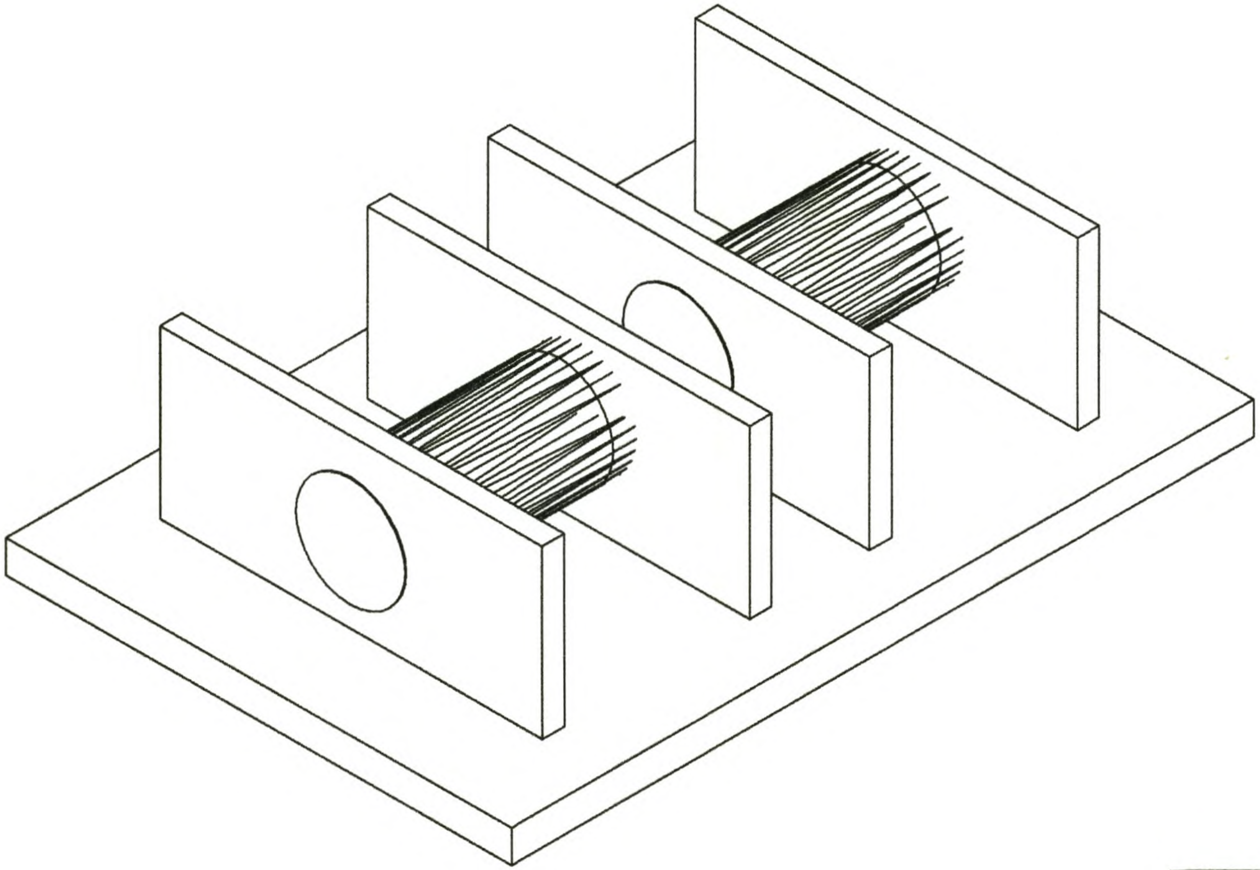
ALL MATERIAL: GRADE 300WA

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TRACK
DRW. NO.: 01-3D-01

NOTE: NOT TO SCALE

12/02/2000



NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
02-01/1
02-01/2
02-02/1

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
02-WS-1
02-WS-2
02-WS-4

WELD DETAIL GIVEN IN DRAWINGS:
02-01/2

ALL MATERIAL: GRADE 300WA

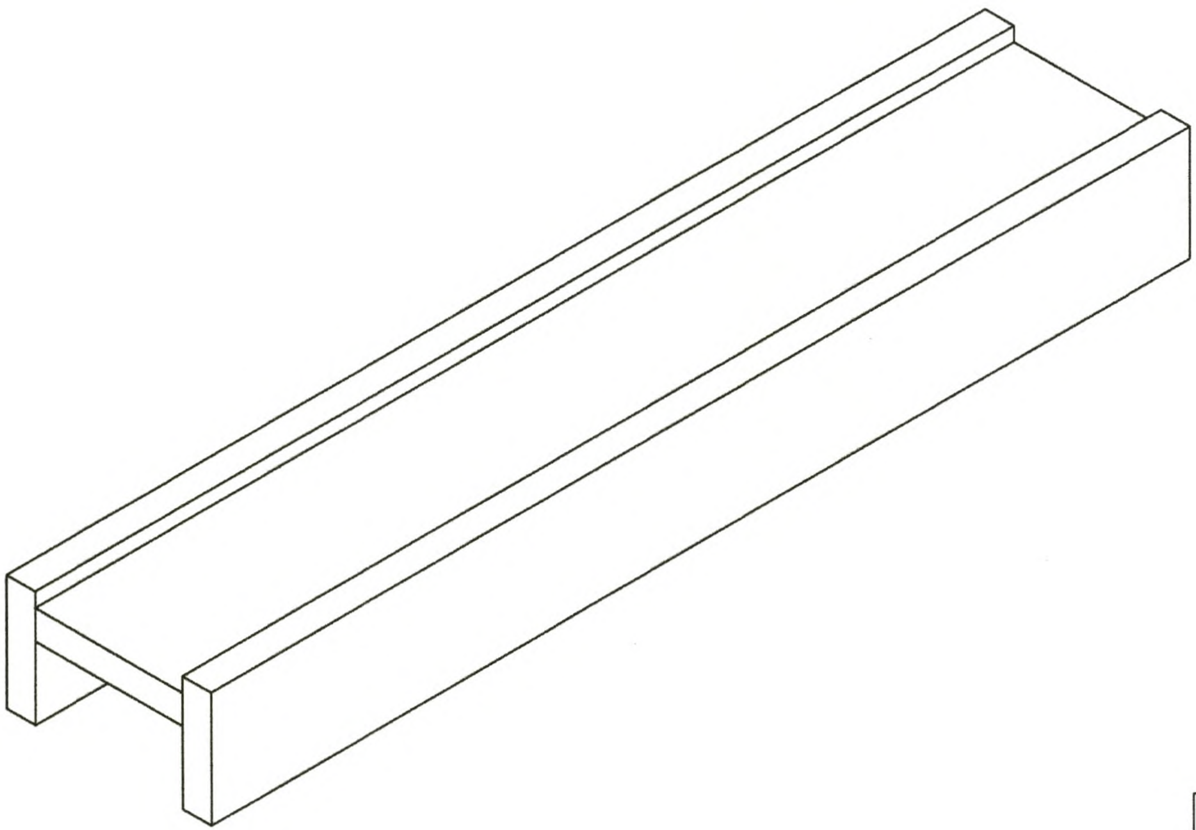
HINGES & PINS

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE
DRW. NO.: 02-3D-01

NOTE: NOT TO SCALE

12/02/2000



NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
02-03/1

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
02-WS-3

WELD DETAIL GIVEN IN DRAWINGS:
02-03/1

ALL MATERIAL: GRADE 300WA

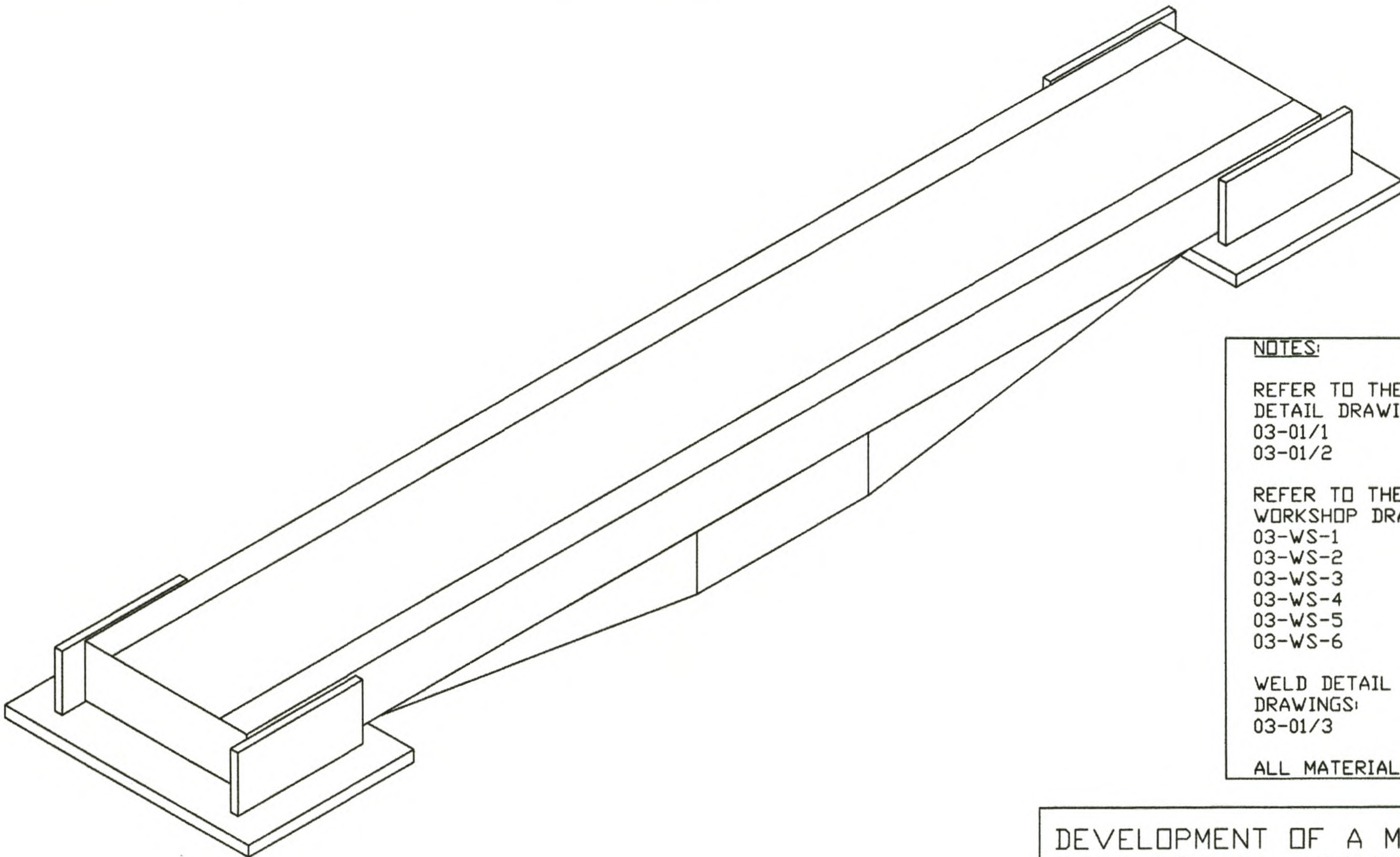
HINGE FIXING BRACKET

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE FIXING BRACKET
DRW. NO.: 02-3D-02

NOTE: NOT TO SCALE

12/02/2000



NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
03-01/1
03-01/2

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
03-WS-1
03-WS-2
03-WS-3
03-WS-4
03-WS-5
03-WS-6

WELD DETAIL GIVEN IN DRAWINGS:
03-01/3

ALL MATERIAL: GRADE 300WA

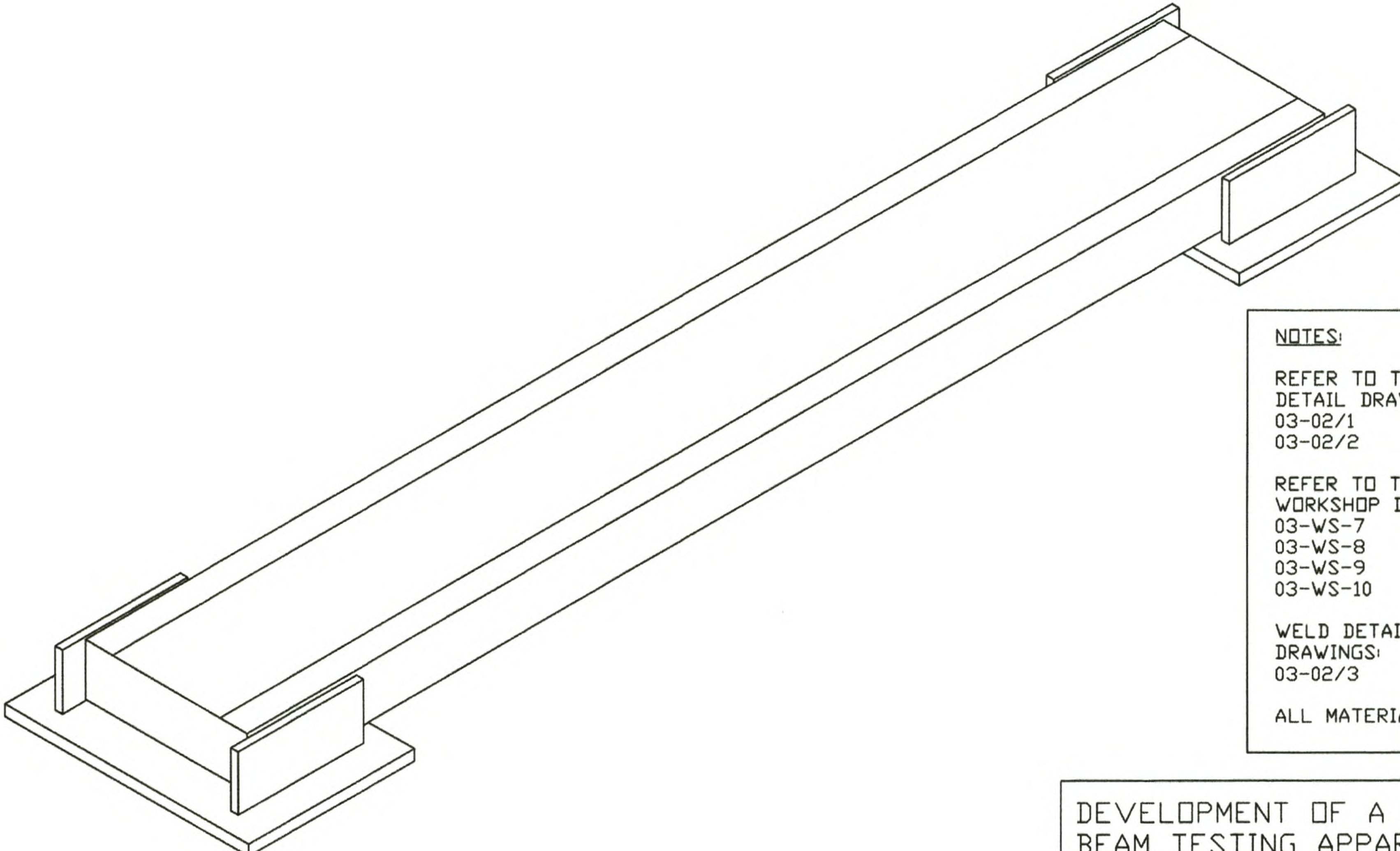
500 kN BRIDGE & HINGES

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: 500kN BRIDGE
DRW. NO.: 03-3D-01

NOTE: NOT TO SCALE

12/02/2000



NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
03-02/1
03-02/2

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
03-WS-7
03-WS-8
03-WS-9
03-WS-10

WELD DETAIL GIVEN IN DRAWINGS:
03-02/3

ALL MATERIAL: GRADE 300WA

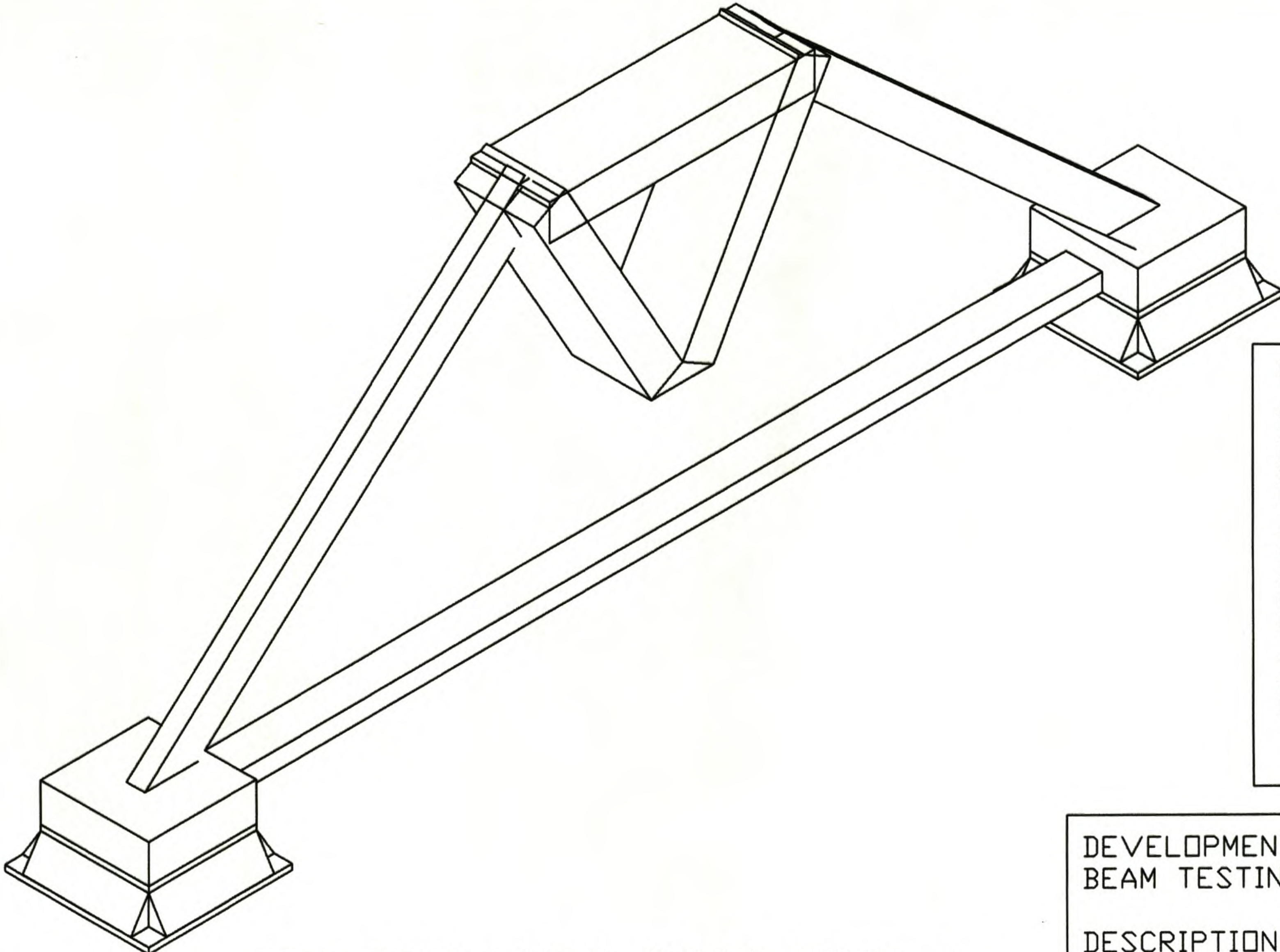
50 kN BRIDGE & HINGES

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: 50kN BRIDGE
DRW. NO.: 03-3D-02

NOTE: NOT TO SCALE

12/02/2000



NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
03-03/1
SR/01 TO SR/27
03-03/2

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
SR/01 TO SR/27
03-WS-11
03-WS-12

WELD DETAIL GIVEN IN DRAWINGS:
03-03/3

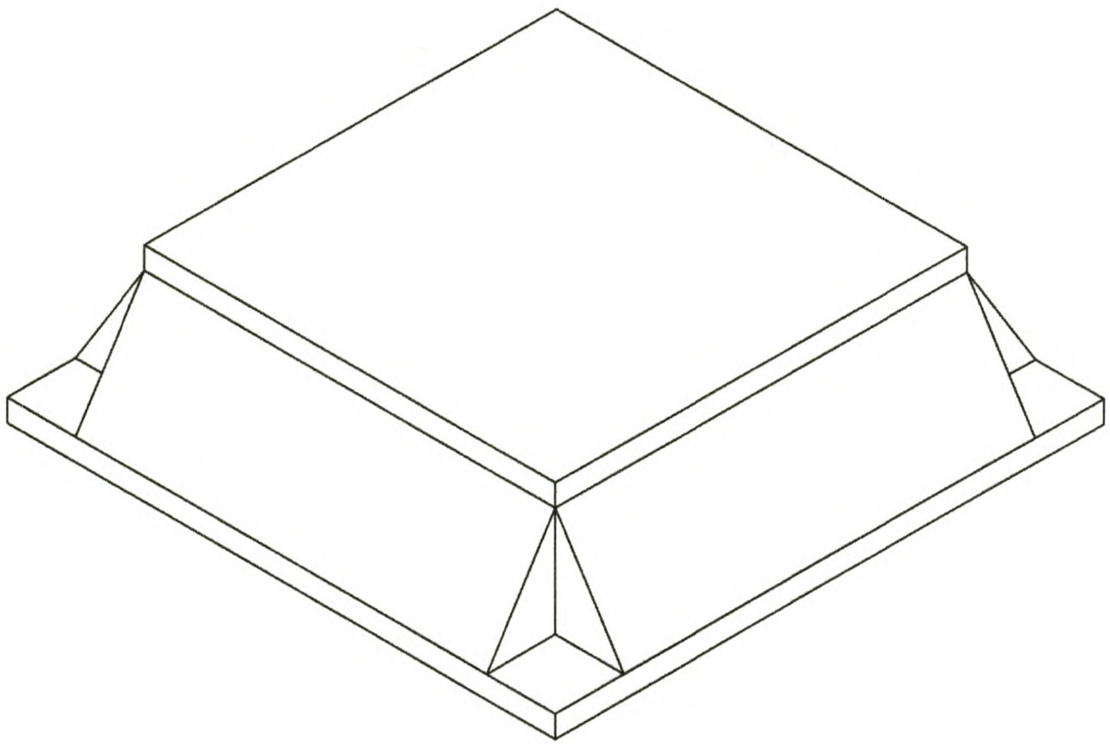
GRAVITY LOAD SIMULATOR & TYPE A CONNECTOR

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: GRAVITY LOAD SIMULATOR
DRW. NO.: 03-3D-01

NOTE: NOT TO SCALE

05/01/2001



NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
03-03/1
03-03/2

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
03-WS-11
03-WS-12

WELD DETAIL GIVEN IN DRAWINGS:
03-03/2

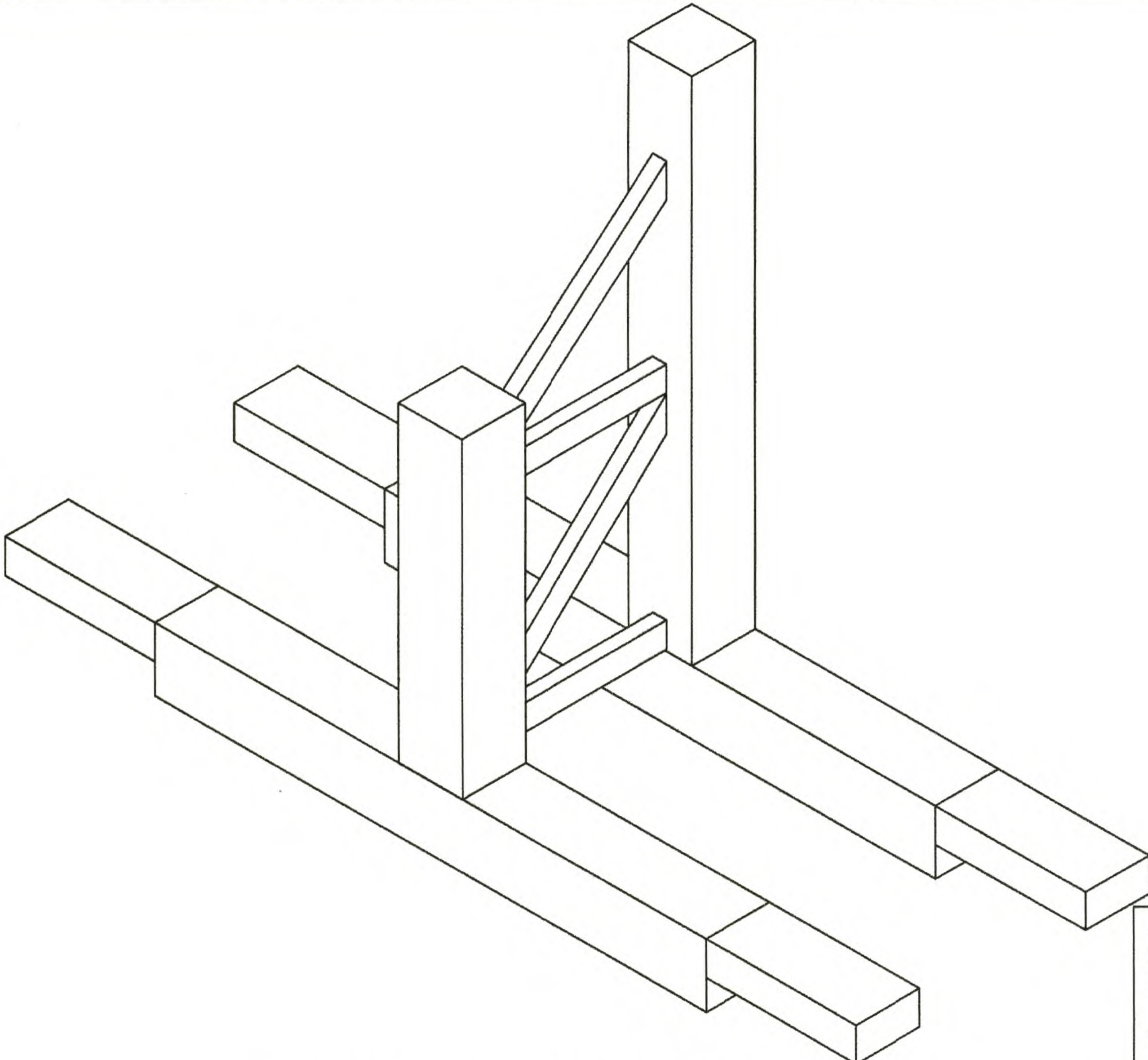
TYPE A CONNECTOR

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TYPE A CONNECTOR
DRW. NO.: 03-3D-04

NOTE: NOT TO SCALE

05/01/2001



VERTICAL SUPPORT AND
HORIZONTAL SUPPORT BRIDGE

NOTES:

REFER TO THE FOLLOWING
DETAIL DRAWINGS:
04-01/1
04-02/2

REFER TO THE FOLLOWING
WORKSHOP DRAWINGS:
04-WS-1 04-WS-5
04-WS-2 04-WS-6
04-WS-3 04-WS-7
04-WS-4 04-WS-8

WELD DETAIL GIVEN IN
DRAWINGS:
04-01/2 04-02/2

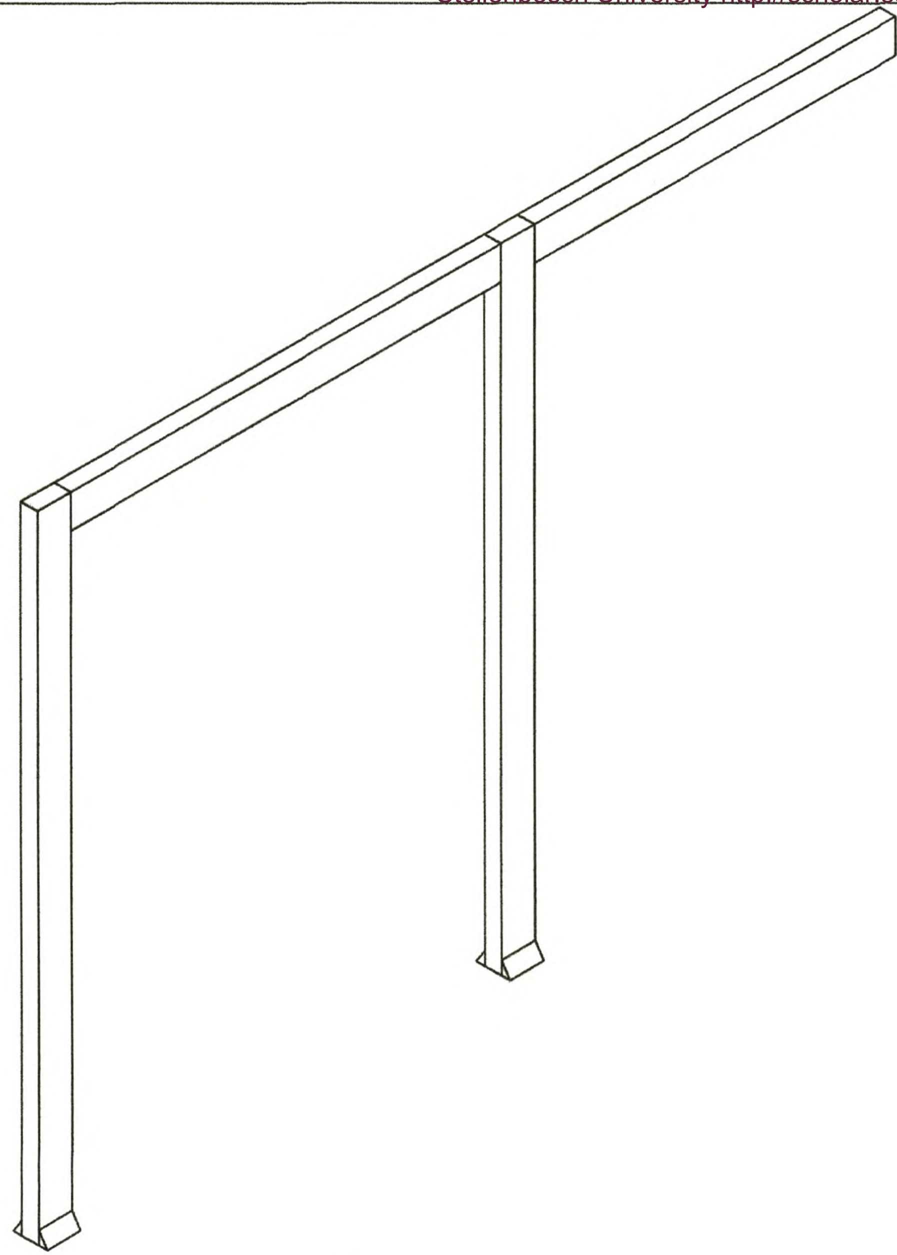
ALL MATERIAL: GRADE 300WA

DEVELOPMENT OF A MULTIPURPOSE
BEAM TESTING APPARATUS

DESCRIPTION: SUPPORT
DRW. NO.: 04-3D-01

NOTE: NOT TO SCALE

12/02/2001



LATTERAL SUPPORTING FRAME

NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
05-01/1

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
05-WS-1
05-WS-2
05-WS-3
05-WS-4

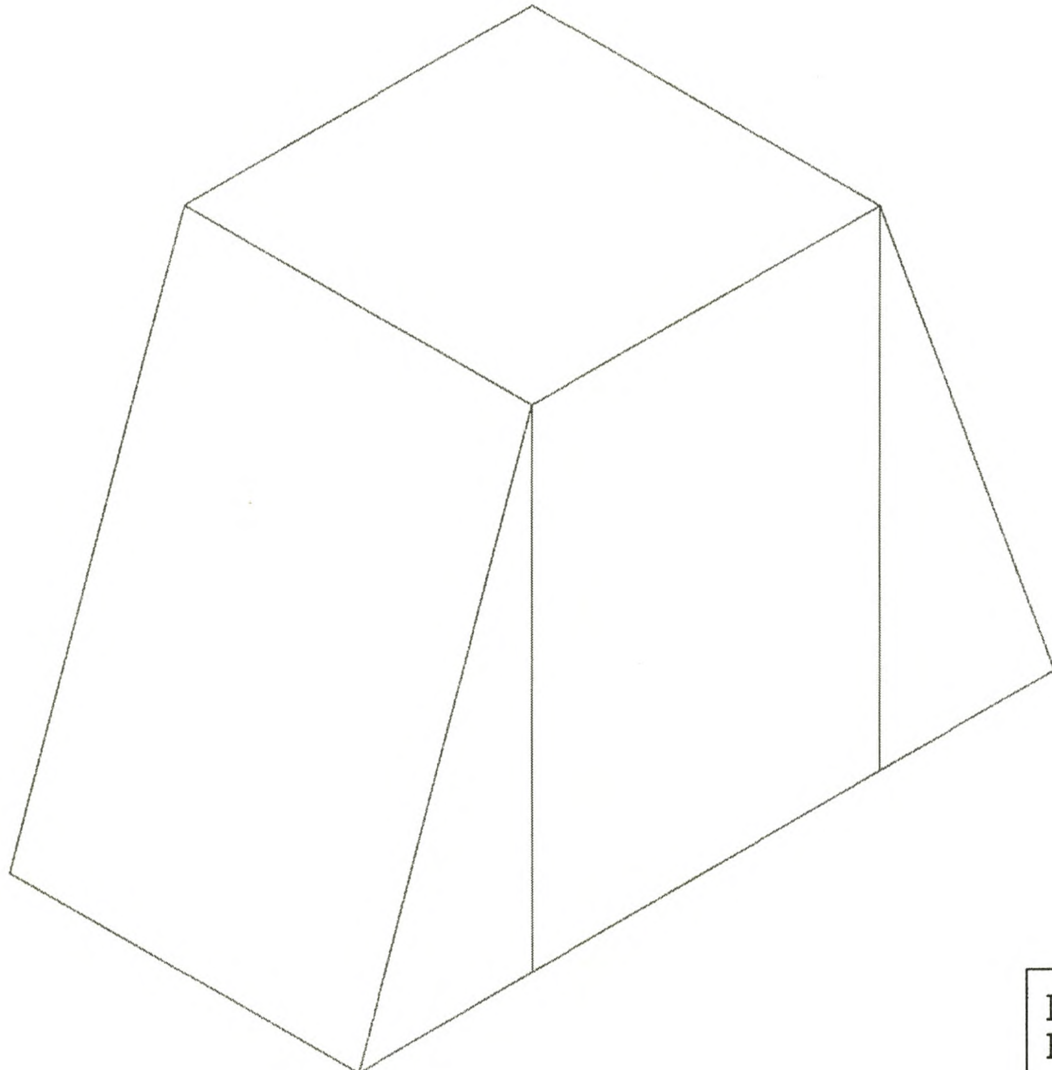
WELD DETAIL GIVEN IN DRAWINGS:
05-01/2

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: LATERAL SUPPORT
DRW. NO.: 05-3D-01

NOTE: NOT TO SCALE

12/02/2000



USE WITH LATERAL
SUPPORTS AND
TRACKS

NOTES:

REFER TO THE FOLLOWING
DETAIL DRAWINGS:
05-02/1

REFER TO THE FOLLOWING
WORKSHOP DRAWINGS:
05-WS-5
05-WS-6

WELD DETAIL:

ALL ROUND 6mm FILLET U.N.O.

ALL MATERIAL: GRADE 300WA

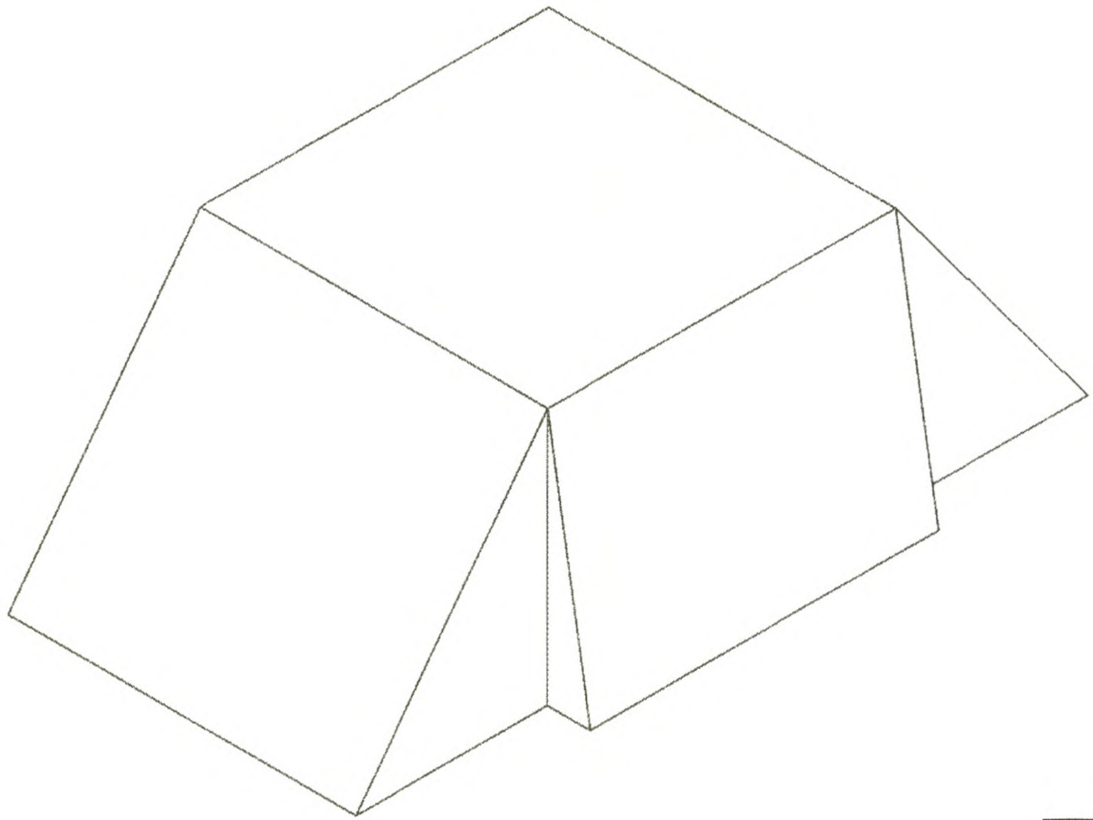
CONNECTOR: TYPE B

DEVELOPMENT OF A MULTIPURPOSE
BEAM TESTING APPARATUS

DESCRIPTION: CONNECTOR: TYPE B
DRW. NO.: 05-3D-02

NOTE: NOT TO SCALE

12/02/2001



USE WITH LATERAL SUPPORTS AND SUPPORTS

NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
05-03/1

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
05-WS-7
05-WS-8

WELD DETAIL:

ALL ROUND 6mm FILLET U.N.O.

ALL MATERIAL: GRADE 300WA

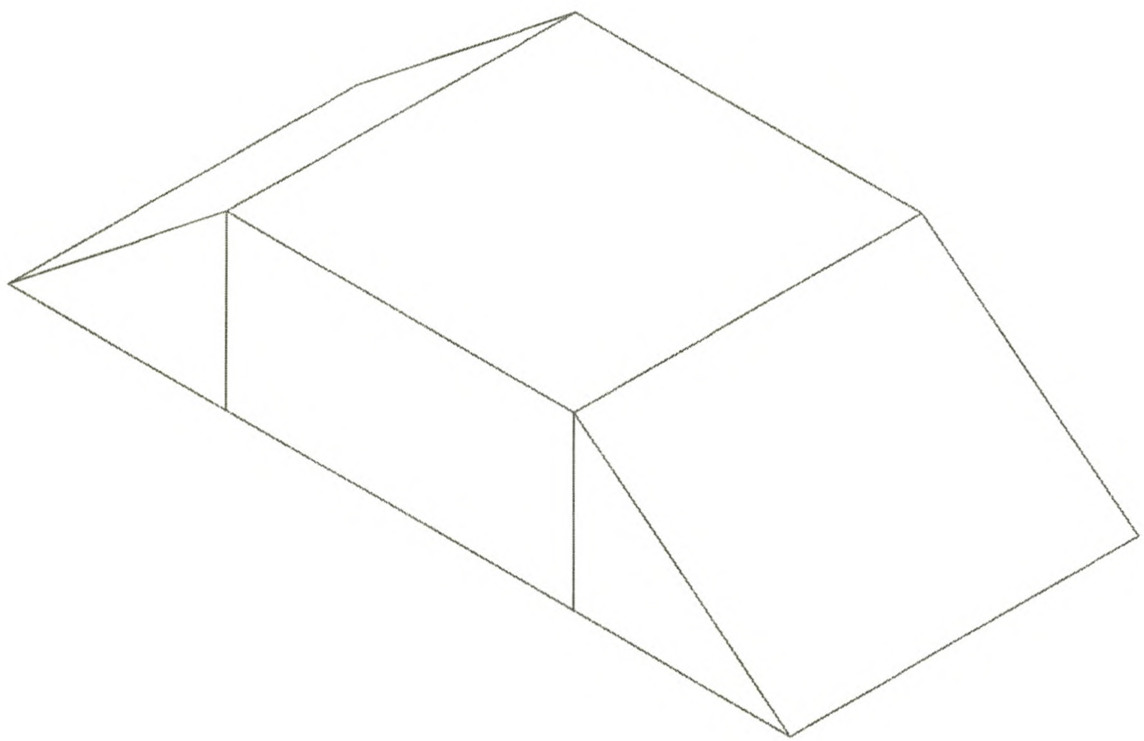
DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: CONNECTOR: TYPE C
DRW. NO.: 05-3D-03

NOTE: NOT TO SCALE

12/02/2001

CONNECTOR: TYPE C



CONNECTOR: TYPE D

USE WITH LATERAL SUPPORTS AND LOAD BRIDGES

NOTES:

REFER TO THE FOLLOWING DETAIL DRAWINGS:
05-04/1

REFER TO THE FOLLOWING WORKSHOP DRAWINGS:
05-WS-9
05-WS-10

WELD DETAIL:

ALL ROUND 6mm FILLET U.N.O.

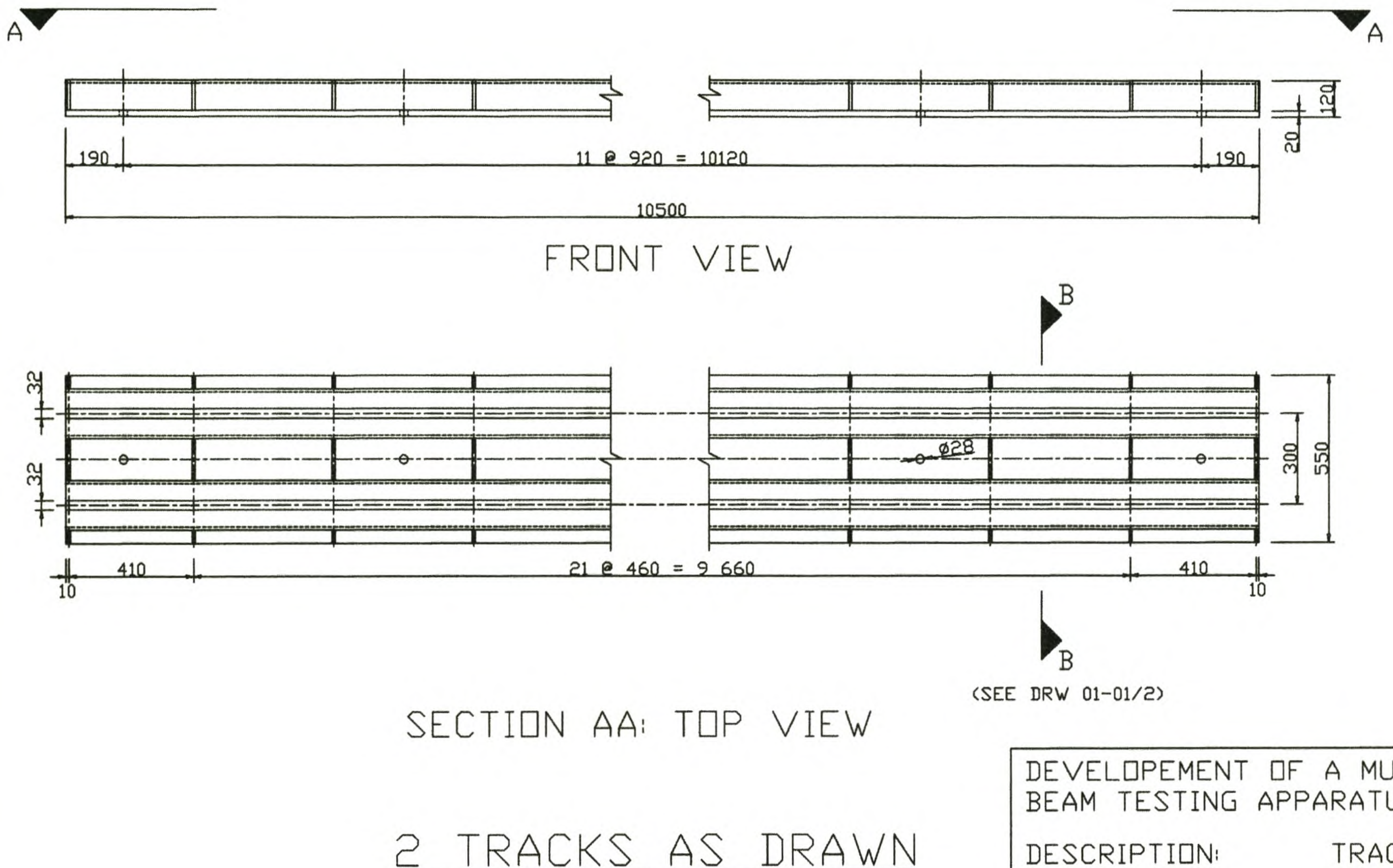
ALL MATERIAL: GRADE 300WA

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: CONNECTOR: TYPE D
DRW. NO.: 05-3D-04

NOTE: NOT TO SCALE

12/02/2001



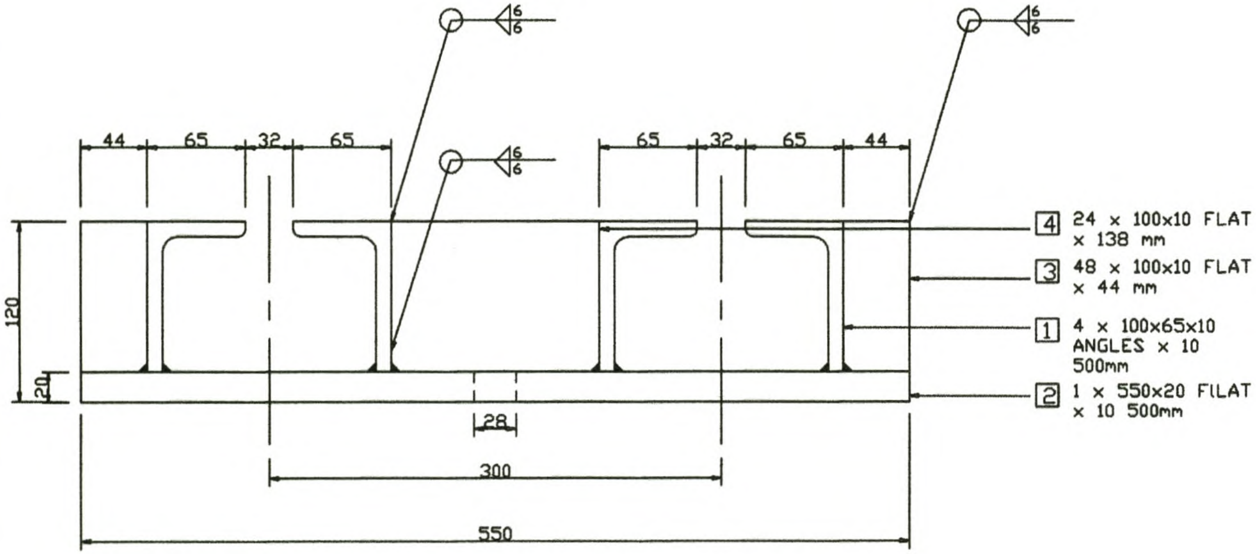
DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TRACK

DRW. NO.: 01-01/1

SCALE 1:20 UNLESS NOTED OTHERWISE

02/08/2000



SECTION BB

NOTES:

WELDING PREPERATION:
AS PER DETAIL DRAWINGS

USE E70XX ELECTRODES

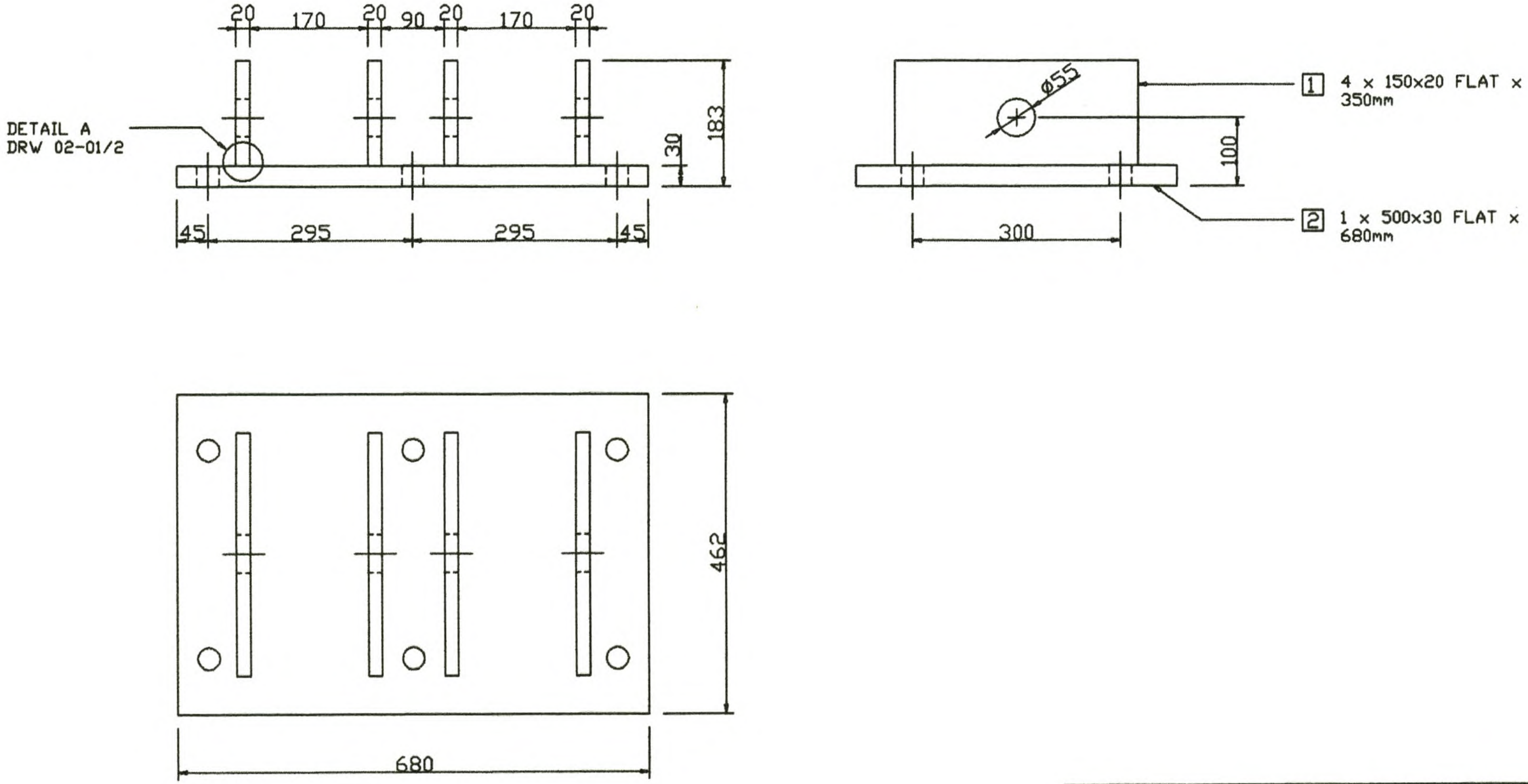
2 TRACKS AS DRAWN

DEVELOPEMENT OF A MULTIPORPOSE BEAM TESTING APPARATUS

DESCRIPTION: TRACK
DRW. NO.: 01-01/2

SCALE 1:5 UNLESS NOTED OTHERWISE

02/09/2000



6 HINGES AS DRAWN

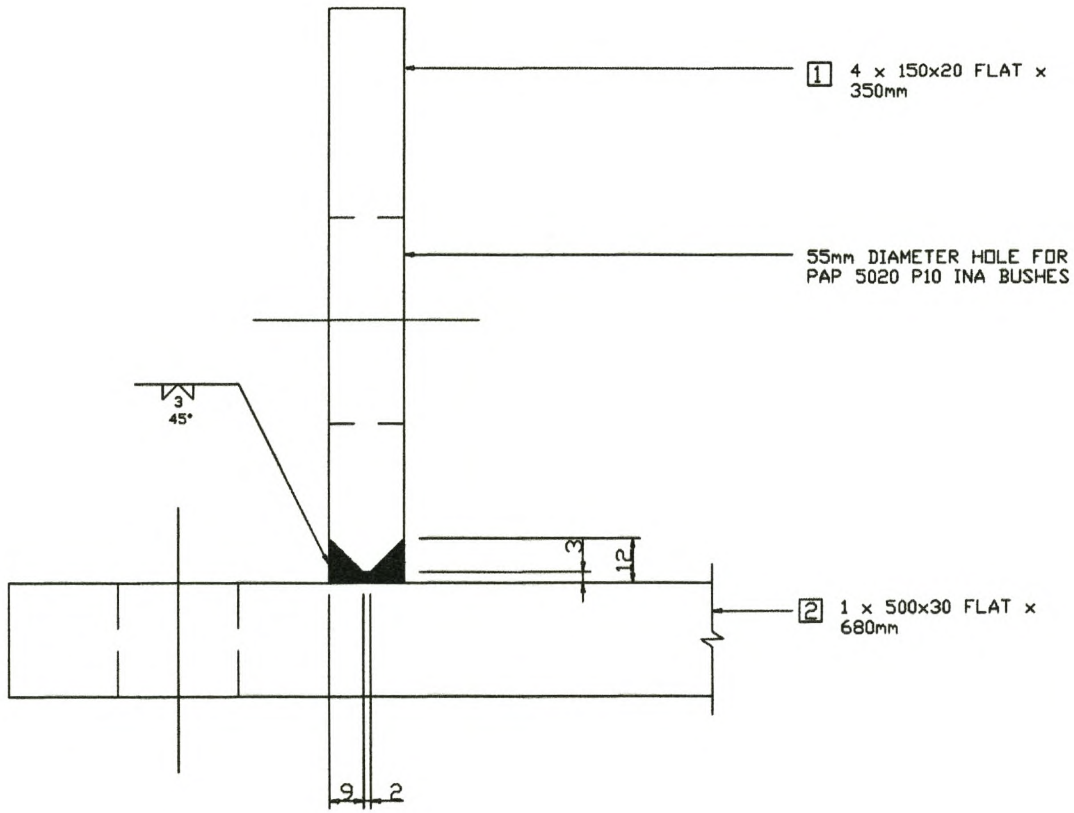
DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE

DRW. NO.: 02-01/1

SCALE 1:10 UNLESS NOTED OTHERWISE

25/10/1999



DETAIL A
REFER TO DRW 02-01/1

NOTES:

WELDING PREPERATION:
AS PER DETAIL DRAWINGS

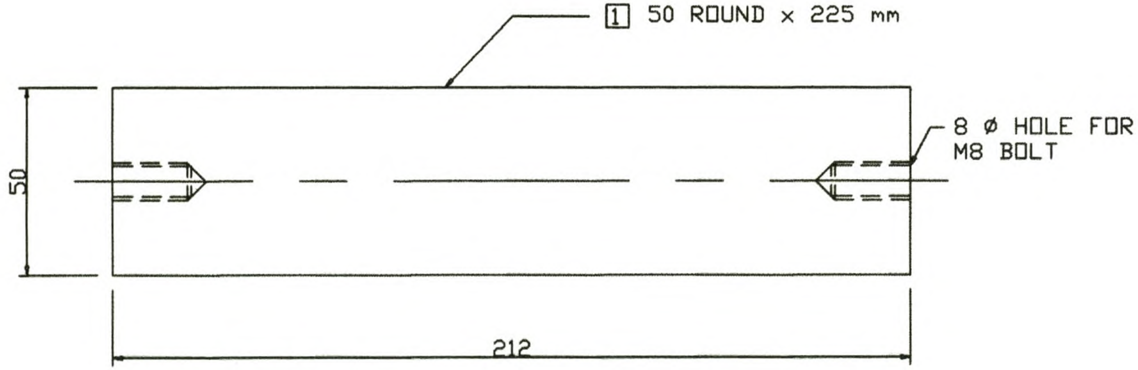
USE E70XX ELECTRODES

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

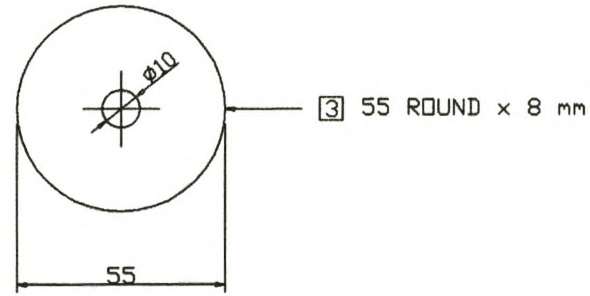
DESCRIPTION: HINGE
DRW. NO.: 02-01/2

SCALE 1:2 UNLESS NOTED OTHERWISE

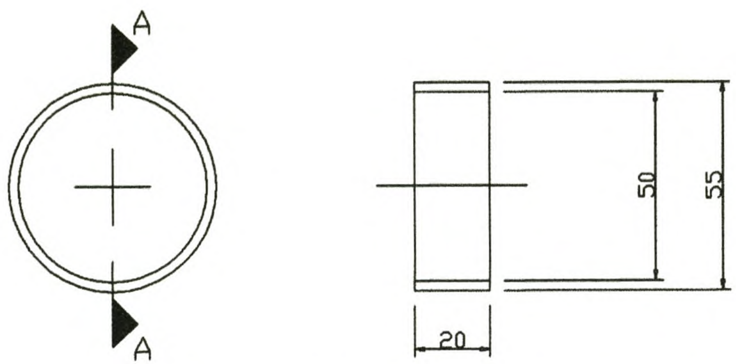
25/10/1999



12 PINS AS DRAWN



24 PIN CAPS



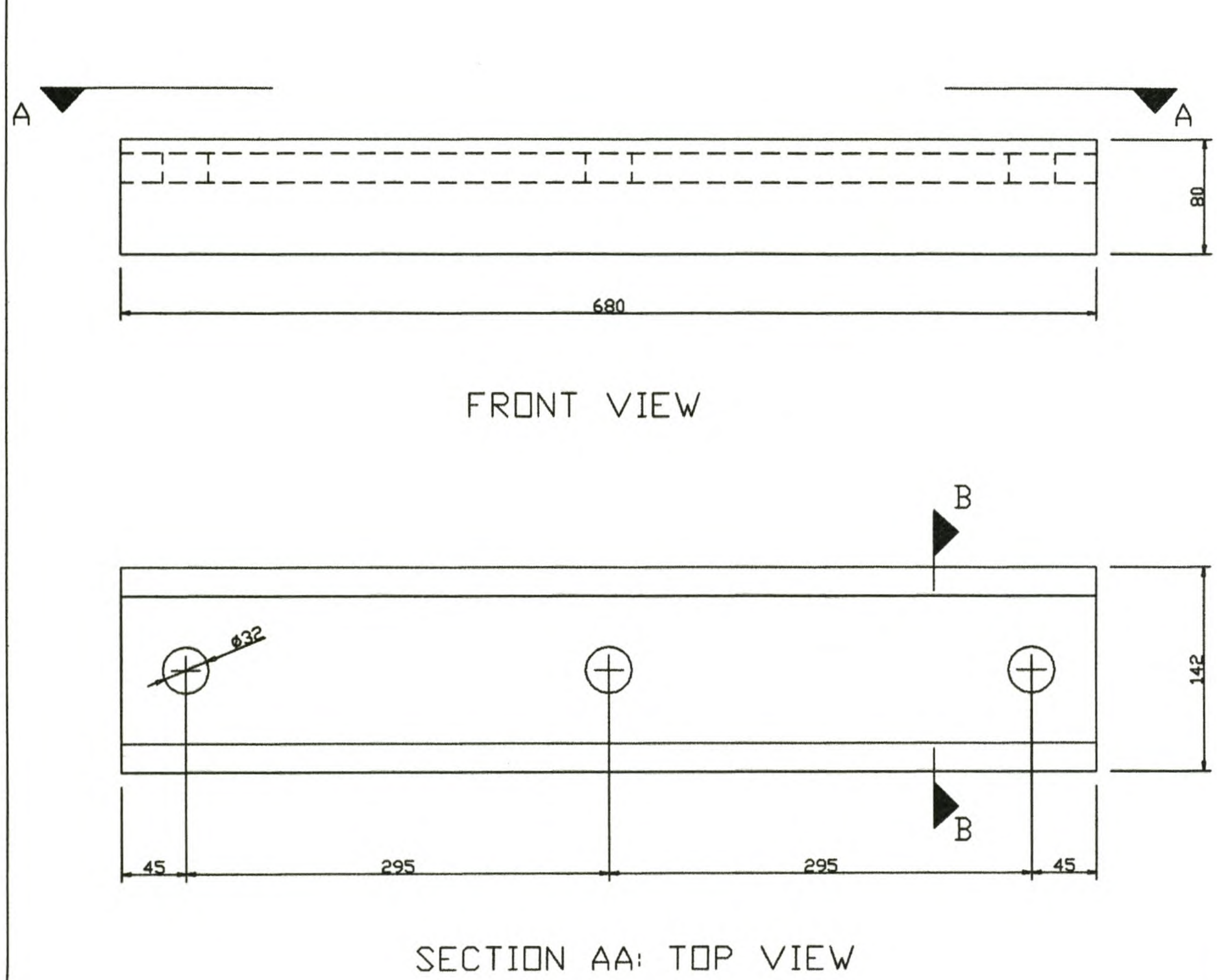
48 PAP 5020 P10 BUSHES

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE PINS & BUSHES
DRW. NO.: 02-02/1

SCALE 1:2 UNLESS NOTED OTHERWISE

05/01/2000



NOTES:

WELDING PREPERATION:
AS PER DETAIL DRAWINGS

USE E70XX ELECTRODES

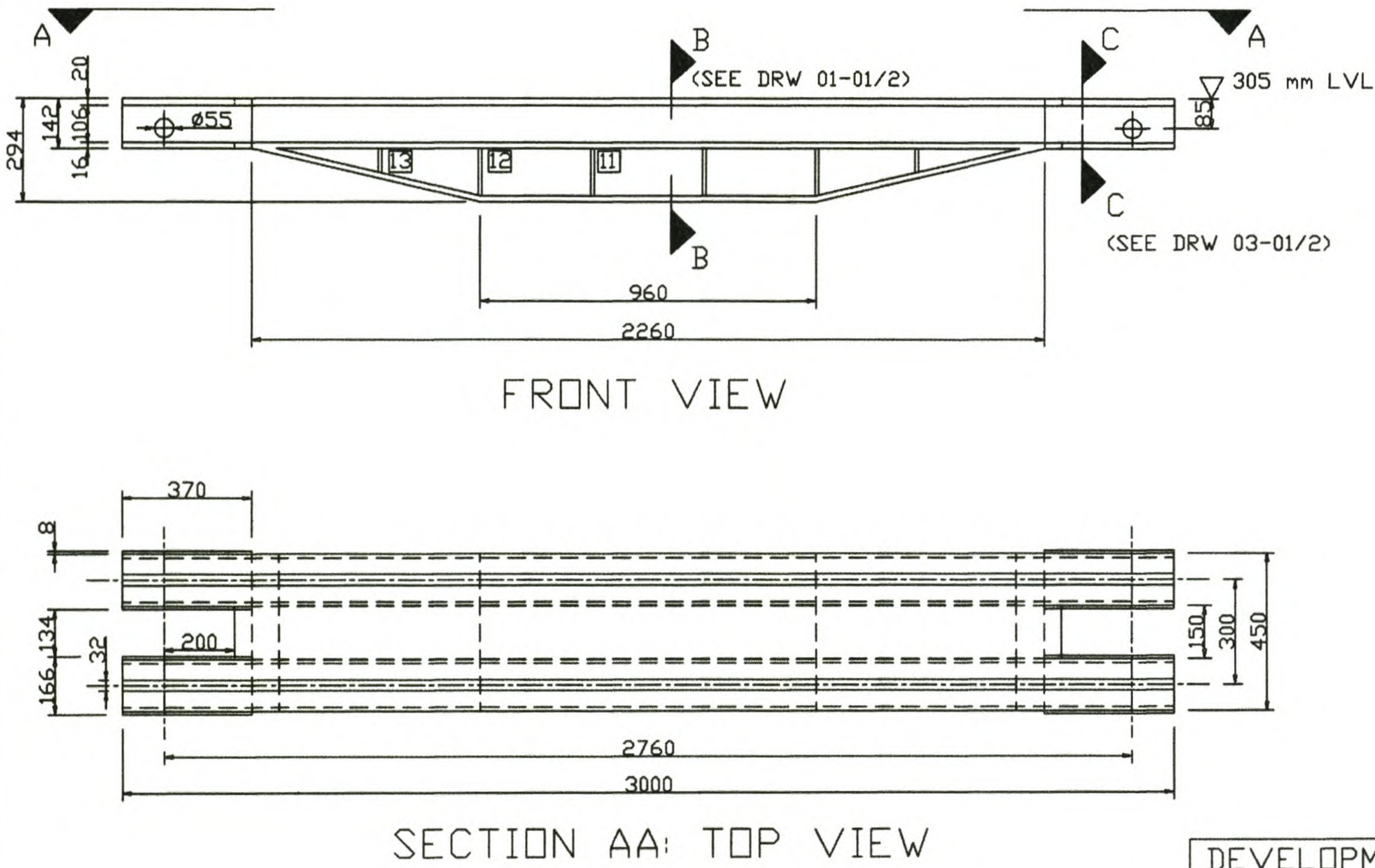
6 HINGE FIXING BRACKETS AS DRAWN

DEVELOPMENT OF A MULTIPORPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE FIXING BRACKET
DRW. NO.: 02-03/1

SCALE 1:5 UNLESS NOTED OTHERWISE

25/10/1999



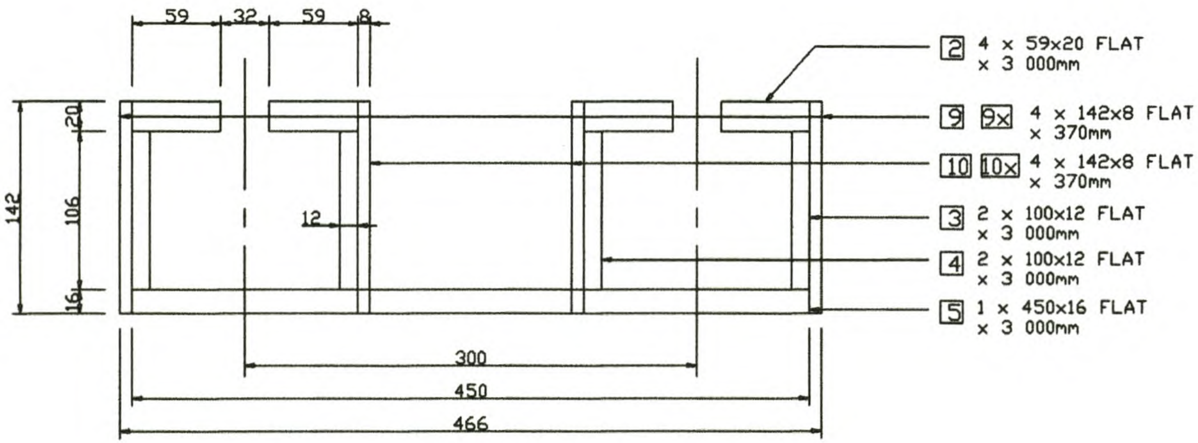
1 BRIDGE AS DRAWN

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

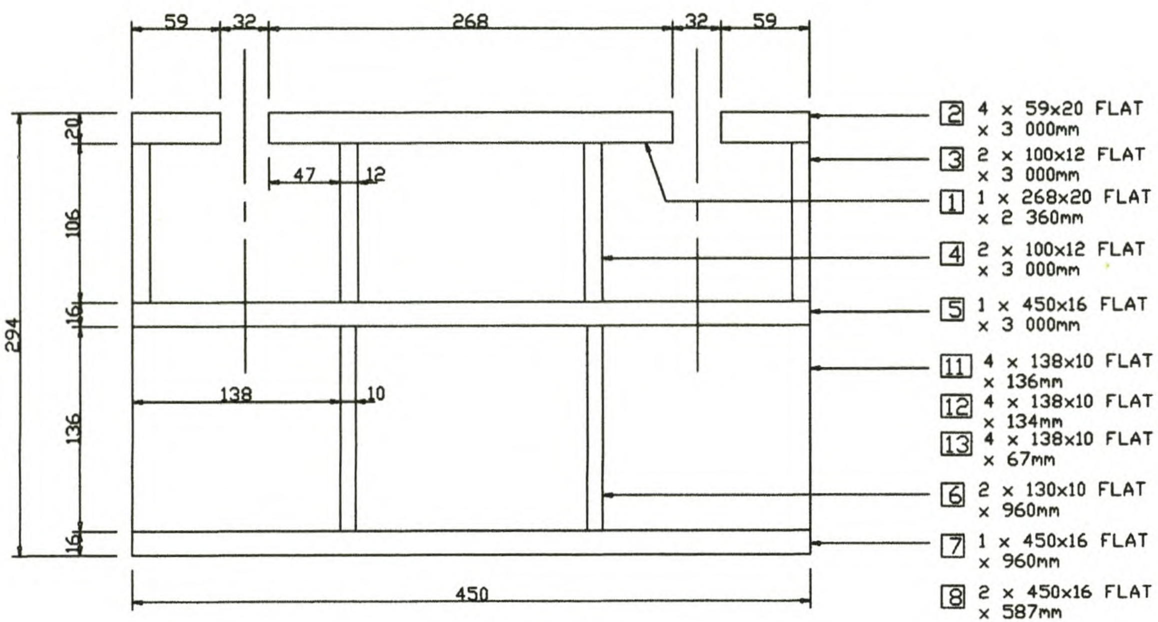
DESCRIPTION: 500 kN BRIDGE
DRW. NO.: 03-01/1

SCALE 1:20 UNLESS NOTED OTHERWISE

02/09/2000



SECTION CC



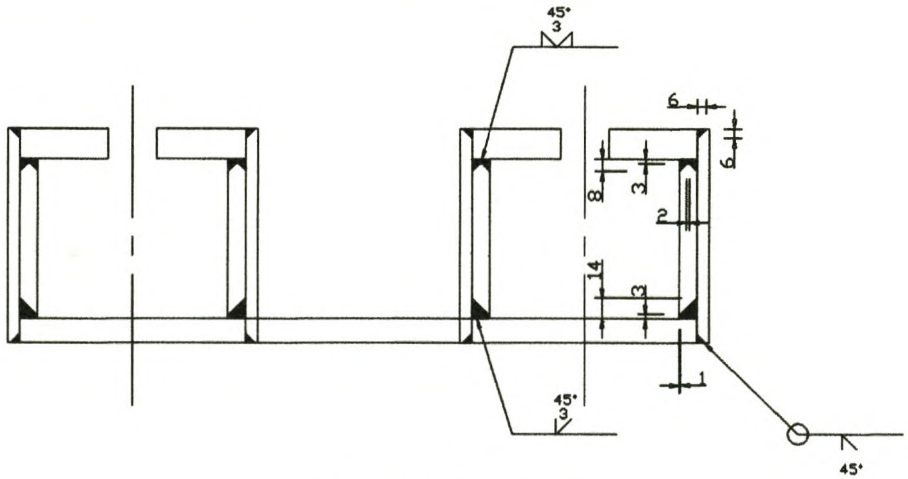
SECTION BB

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

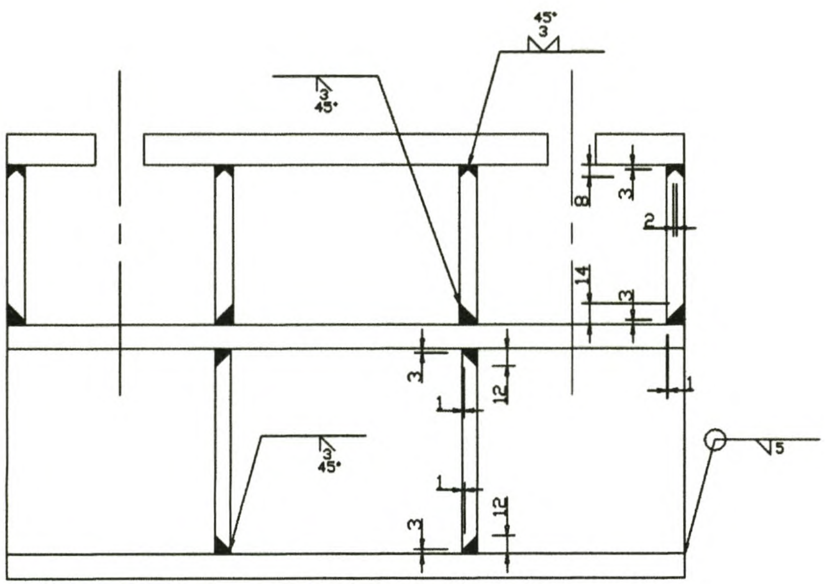
DESCRIPTION: BRIDGE
DRW. NO.: 03-01/2

SCALE 1:5 UNLESS NOTED OTHERWISE

25/01/2000



SECTION CC



SECTION BB

NOTES:

WELDING PREPERATION:
AS PER DETAIL DRAWINGS

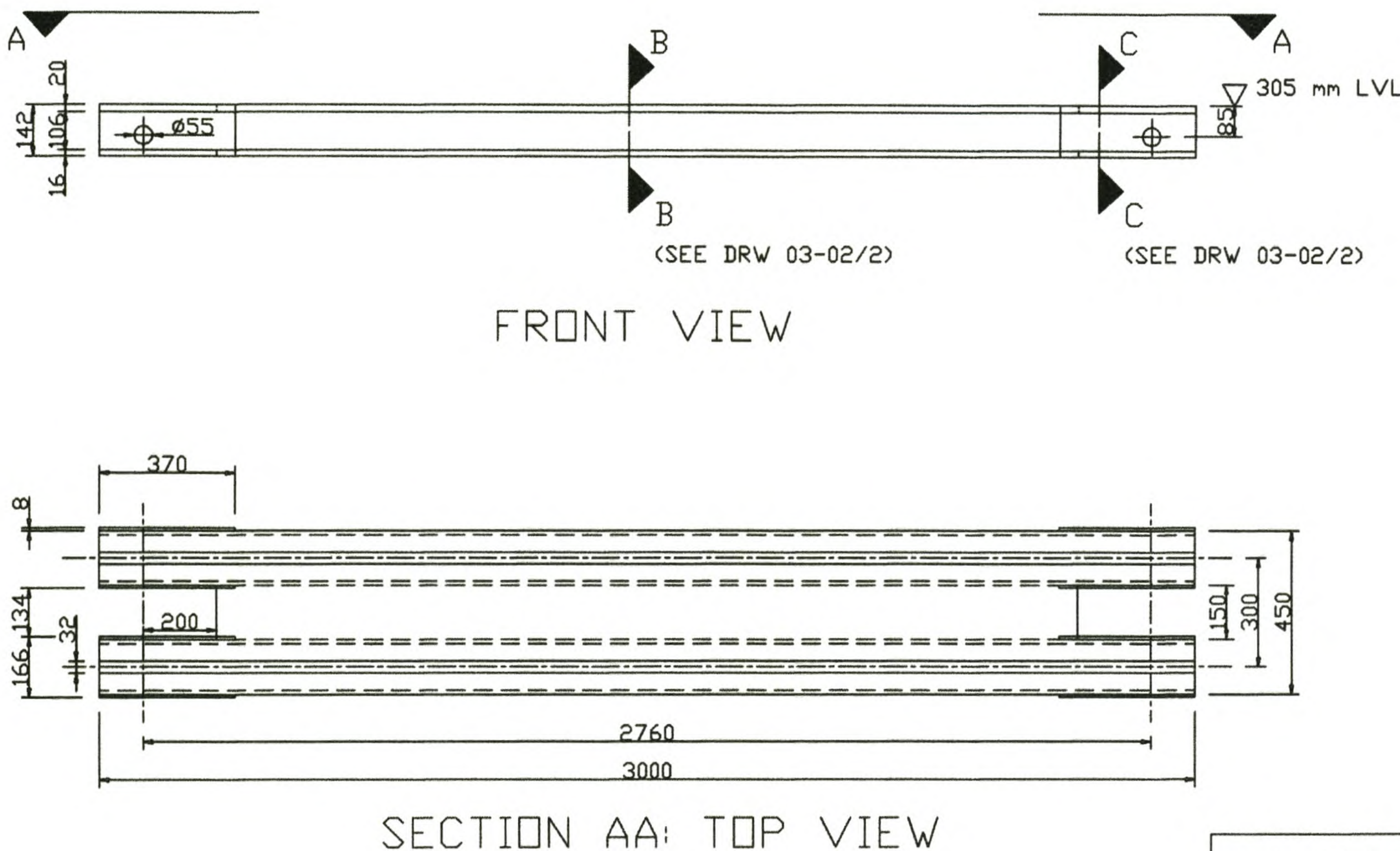
USE E70XX ELECTRODES

DEVELOPMENT OF A MULTIPURPOSE
BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE
DRW. NO.: 03-01/3

SCALE 1:5 UNLESS NOTED OTHERWISE

25/01/2000



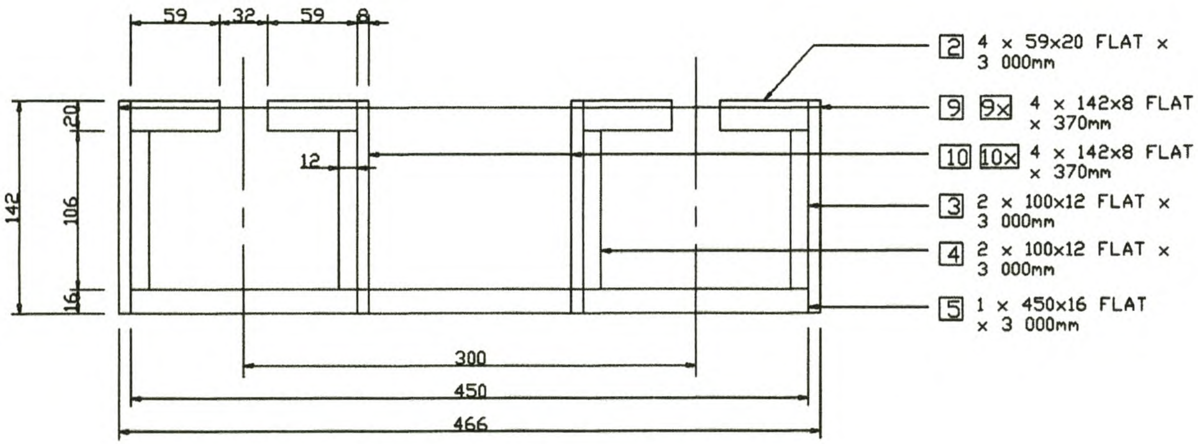
2 BRIDGE AS DRAWN

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

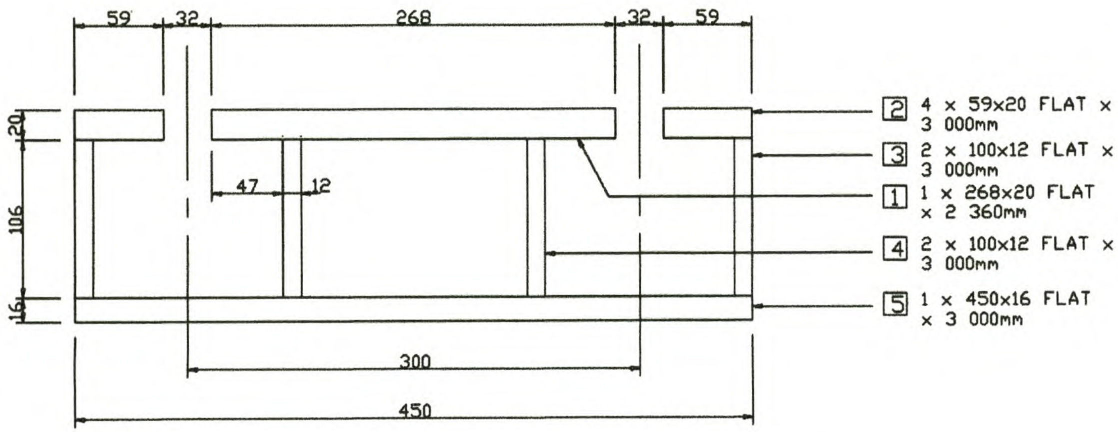
DESCRIPTION: 50 kN BRIDGE
DRW. NO.: 03-02/1

SCALE 1:20 UNLESS NOTED OTHERWISE

02/09/2000



SECTION CC



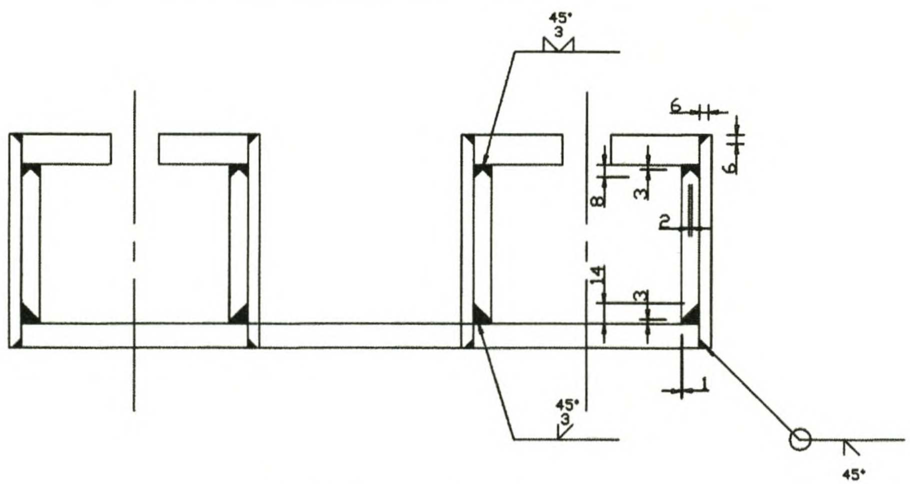
SECTION BB

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

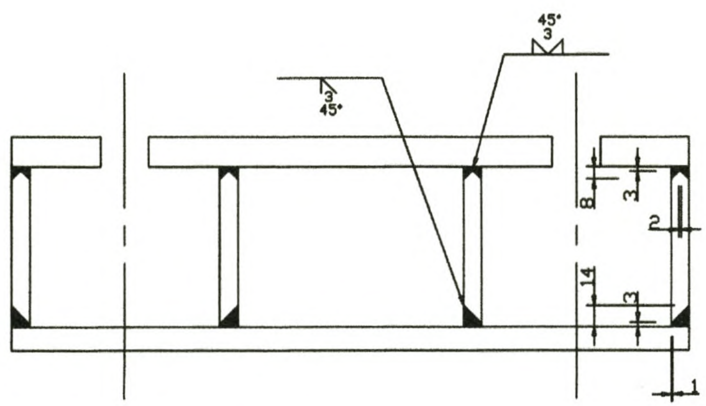
DESCRIPTION: BRIDGE
DRW. NO.: 03-02/2

SCALE 1:5 UNLESS NOTED OTHERWISE

25/01/2000



SECTION CC



SECTION BB

NOTES:

WELDING PREPERATION:
AS PER DETAIL DRAWINGS

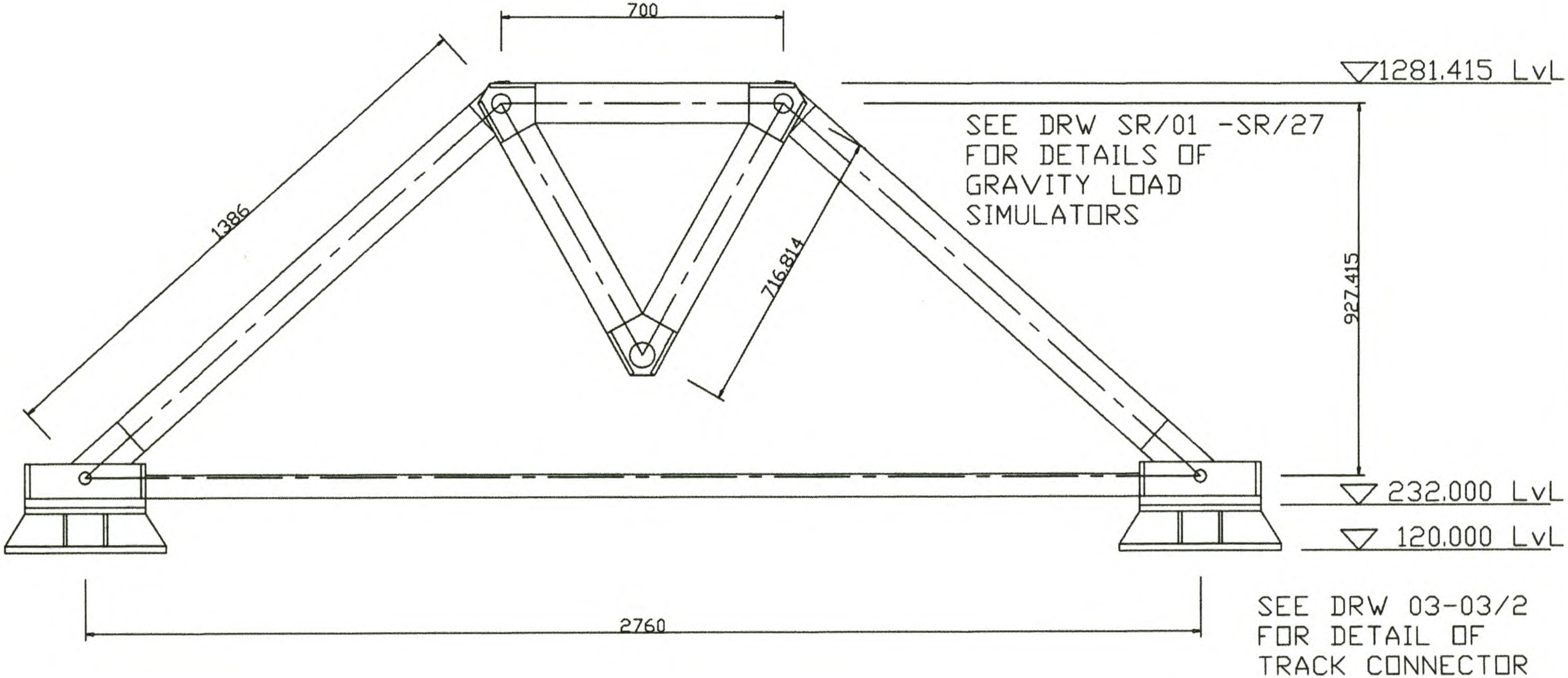
USE E70XX ELECTRODES

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE
DRW. NO.: 03-02/3

SCALE 1:5 UNLESS NOTED OTHERWISE

25/01/2000



2 GRAVITY LOAD SIMULATORS

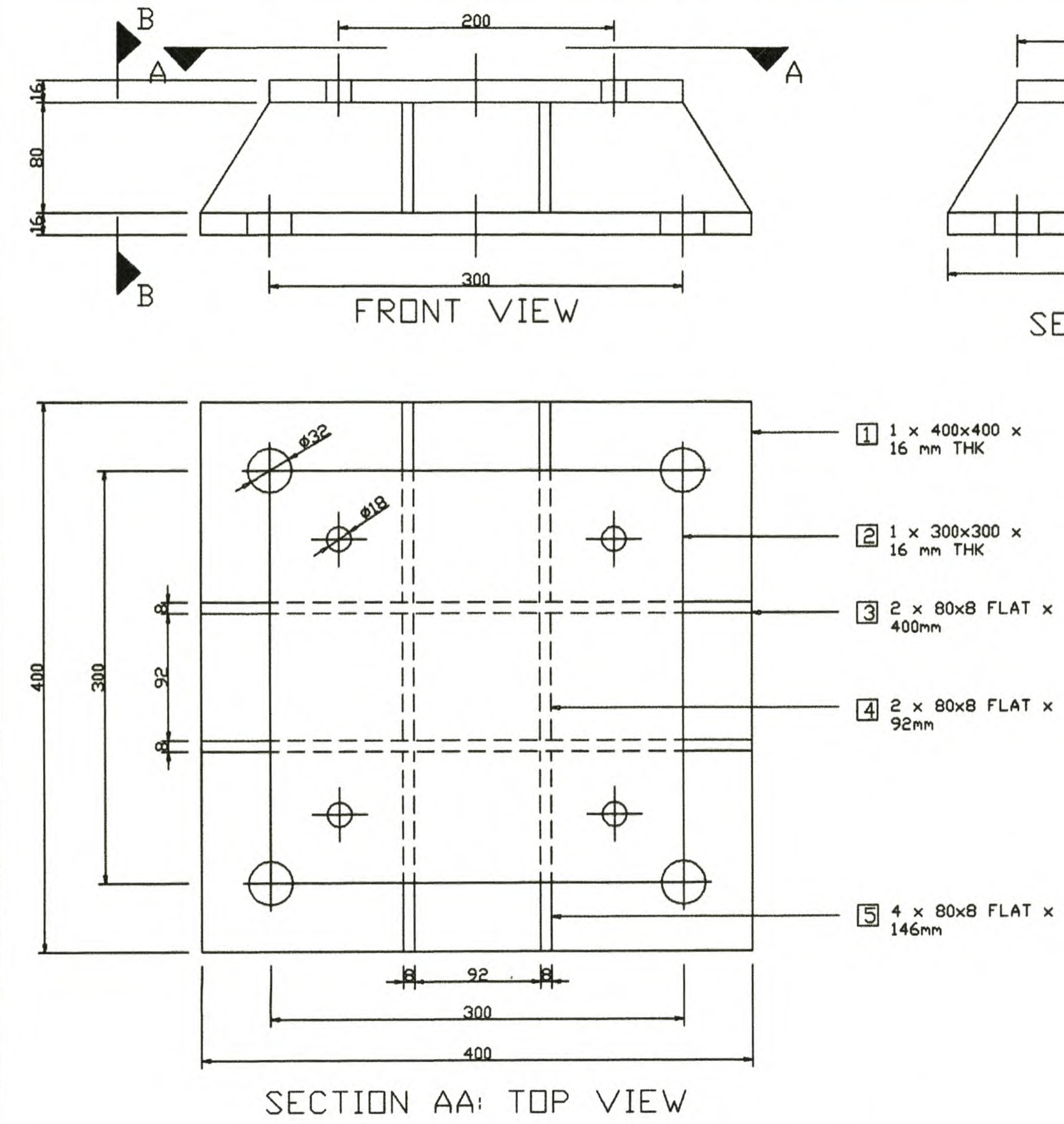
DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: GRAVITY LOAD SIMULATOR

DRW. NO.: 03-03/1

SCALE 1:15 UNLESS NOTED OTHERWISE

03/03/2001



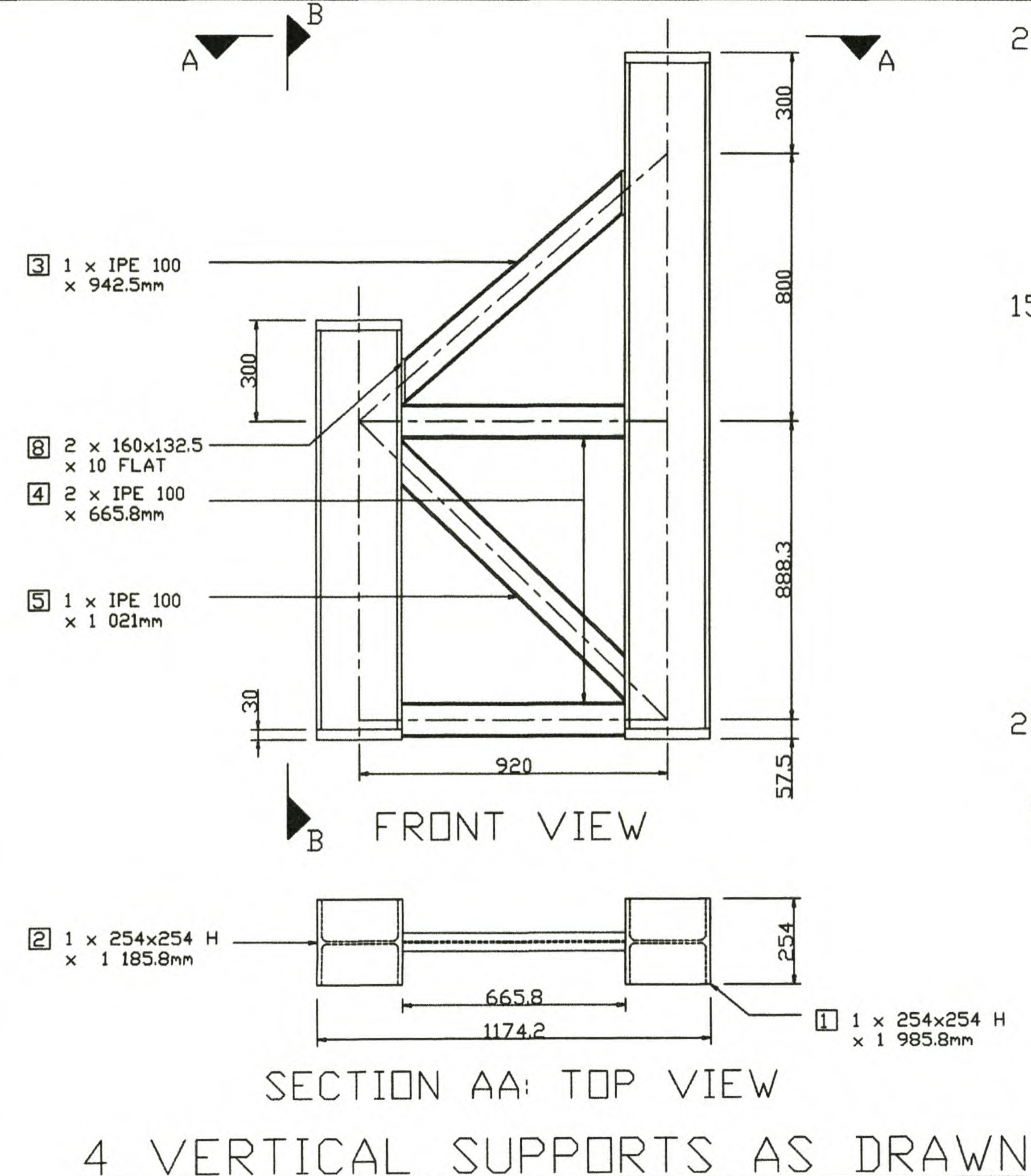
4 TYPE A CONNECTORS AS DRAWN

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TYPE A CONNECTOR
DRW. NO.: 03-03/2

SCALE 1:5 UNLESS NOTED OTHERWISE

25/10/1999



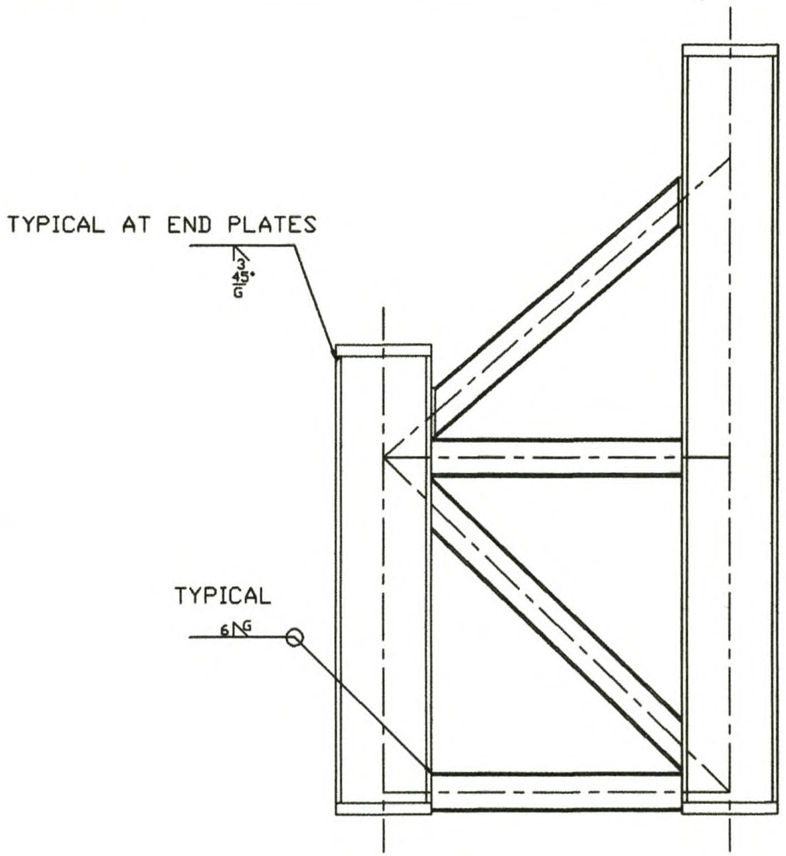
DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: VERTICAL SUPPORTS

DRW. NO.: 04-01/1

SCALE 1:20 UNLESS NOTED OTHERWISE

25/20/1999



FRONT VIEW

NOTES:

WELDING PREPERATION:
AS PER DETAIL DRAWINGS

6mm FILLET ALL ROUND U.N.O.

USE E70XX ELECTRODES

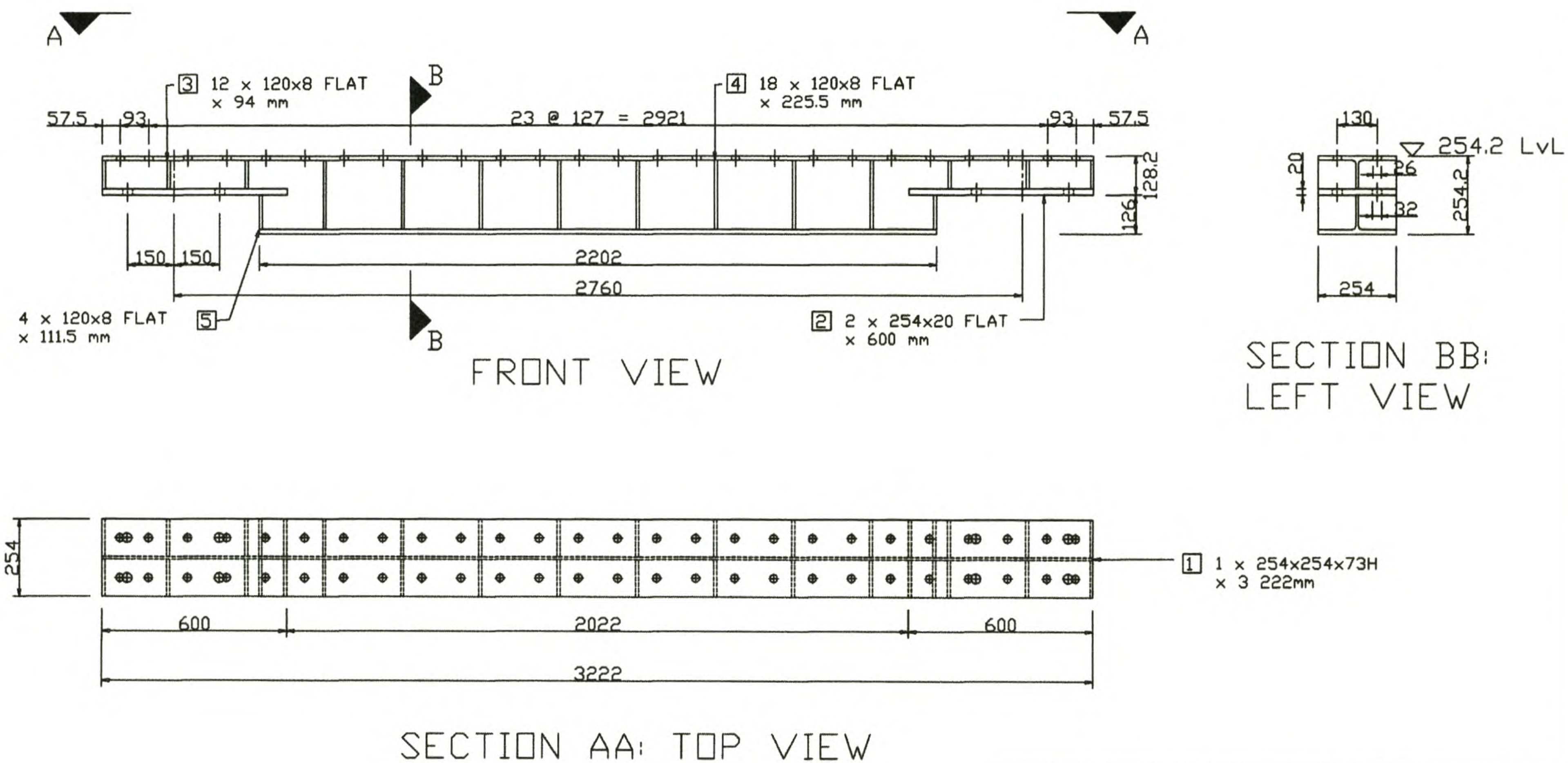
VERTICAL SUPPORTS

DEVELOPMENT OF A MULTIPURPOSE
BEAM TESTING APPARATUS

DESCRIPTION: VERTICAL SUPPORTS
DRW. NO.: 04-01/2

SCALE 1:20 UNLESS NOTED OTHERWISE

25/20/1999



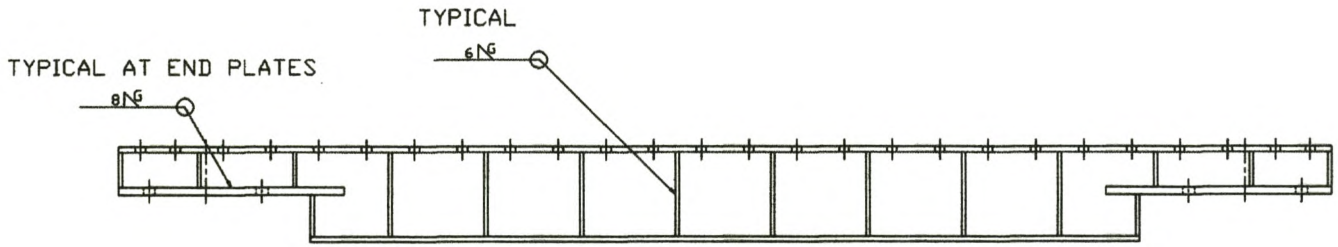
DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: SUPPORT BRIDGE
DRW. NO.: 04-02/1

SCALE 1:20 UNLESS NOTED OTHERWISE

25/10/1999

4 SUPPORT BRIDGES AS DRAWN



FRONT VIEW

NOTES:

WELDING PREPERATION:
AS PER DETAIL DRAWINGS

6mm FILLET ALL ROUND U.N.O.

USE E70XX ELECTRODES

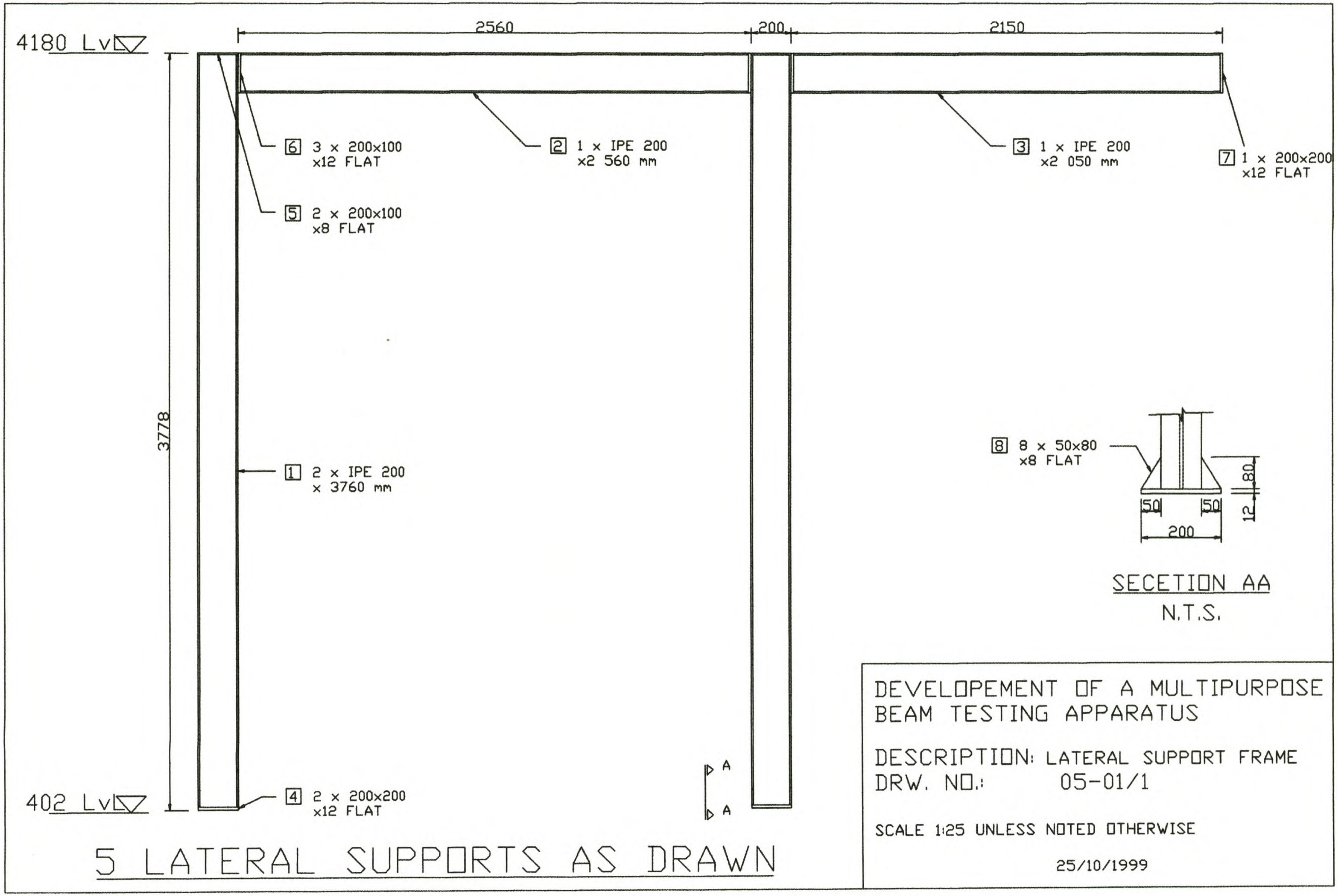
DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: SUPPORT BRIDGE
DRW. NO.: 04-02/2

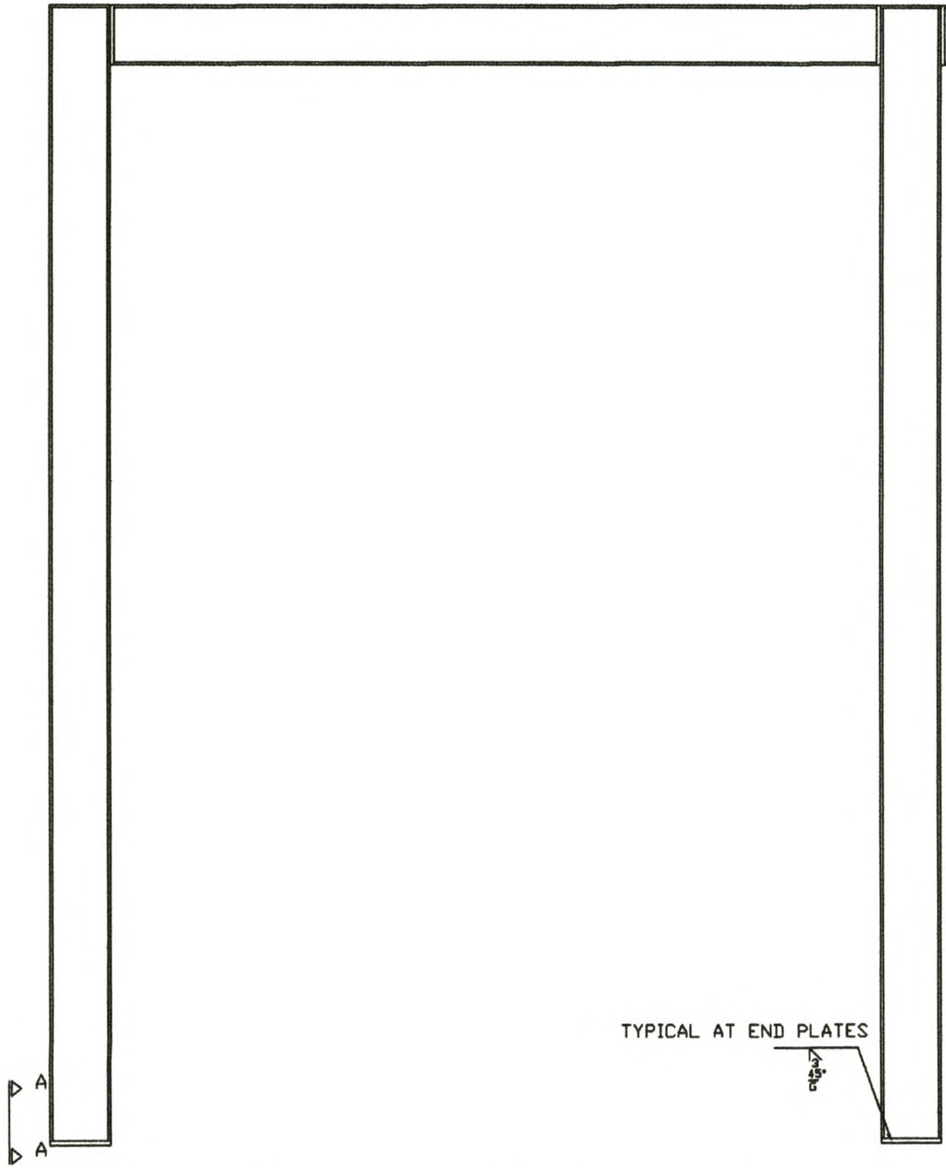
SCALE 1:20 UNLESS NOTED OTHERWISE

25/10/1999

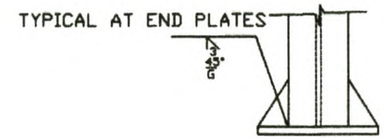
SUPPORT BRIDGE



2560
200
2150
4180 Lv
402 Lv
3778
6 3 x 200x100 x12 FLAT
5 2 x 200x100 x8 FLAT
2 1 x IPE 200 x2 560 mm
3 1 x IPE 200 x2 050 mm
7 1 x 200x200 x12 FLAT
1 2 x IPE 200 x 3760 mm
4 2 x 200x200 x12 FLAT
8 8 x 50x80 x8 FLAT
50
50
200
80
12
A
A
SECETION AA
N.T.S.
5 LATERAL SUPPORTS AS DRAWN
DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS
DESCRIPTION: LATERAL SUPPORT FRAME
DRW. NO.: 05-01/1
SCALE 1:25 UNLESS NOTED OTHERWISE
25/10/1999



LATERAL SUPPORTS



SECETION AA
N.T.S.

NOTES:

WELDING PREPERATION:
AS PER DETAIL DRAWINGS

6mm FILLET ALL ROUND U.N.O.

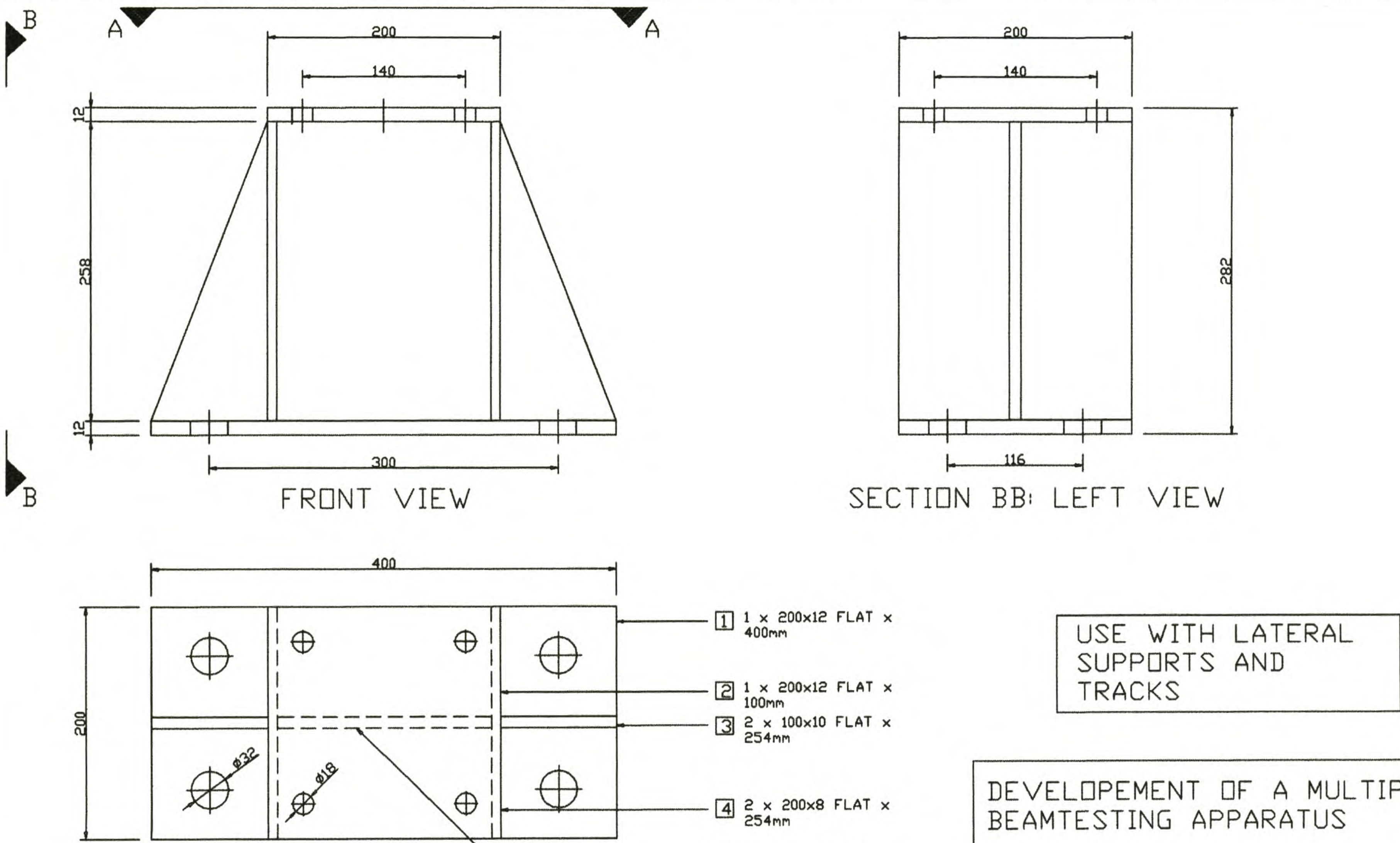
USE E70XX ELECTRODES

DEVELOPEMENT OF A MULTIPURPOSE
BEAM TESTING APPARATUS

DESCRIPTION: LATERAL SUPPORT FRAME
DRW. NO.: 05-01/2

SCALE 1:25 UNLESS NOTED OTHERWISE

25/10/1999



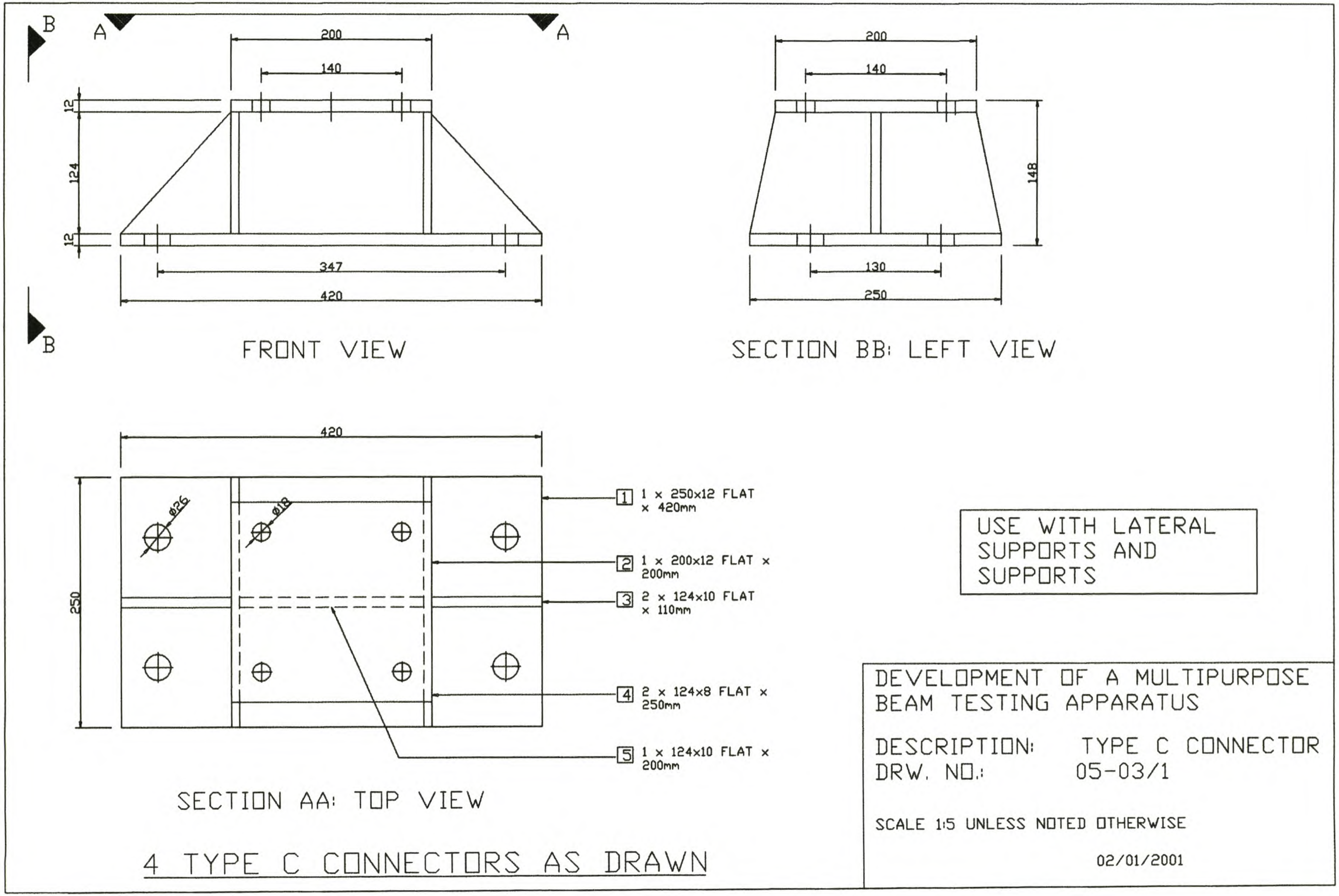
6 TYPE B CONNECTORS AS DRAWN

DEVELOPEMENT OF A MULTIPURPOSE BEAMTESTING APPARATUS

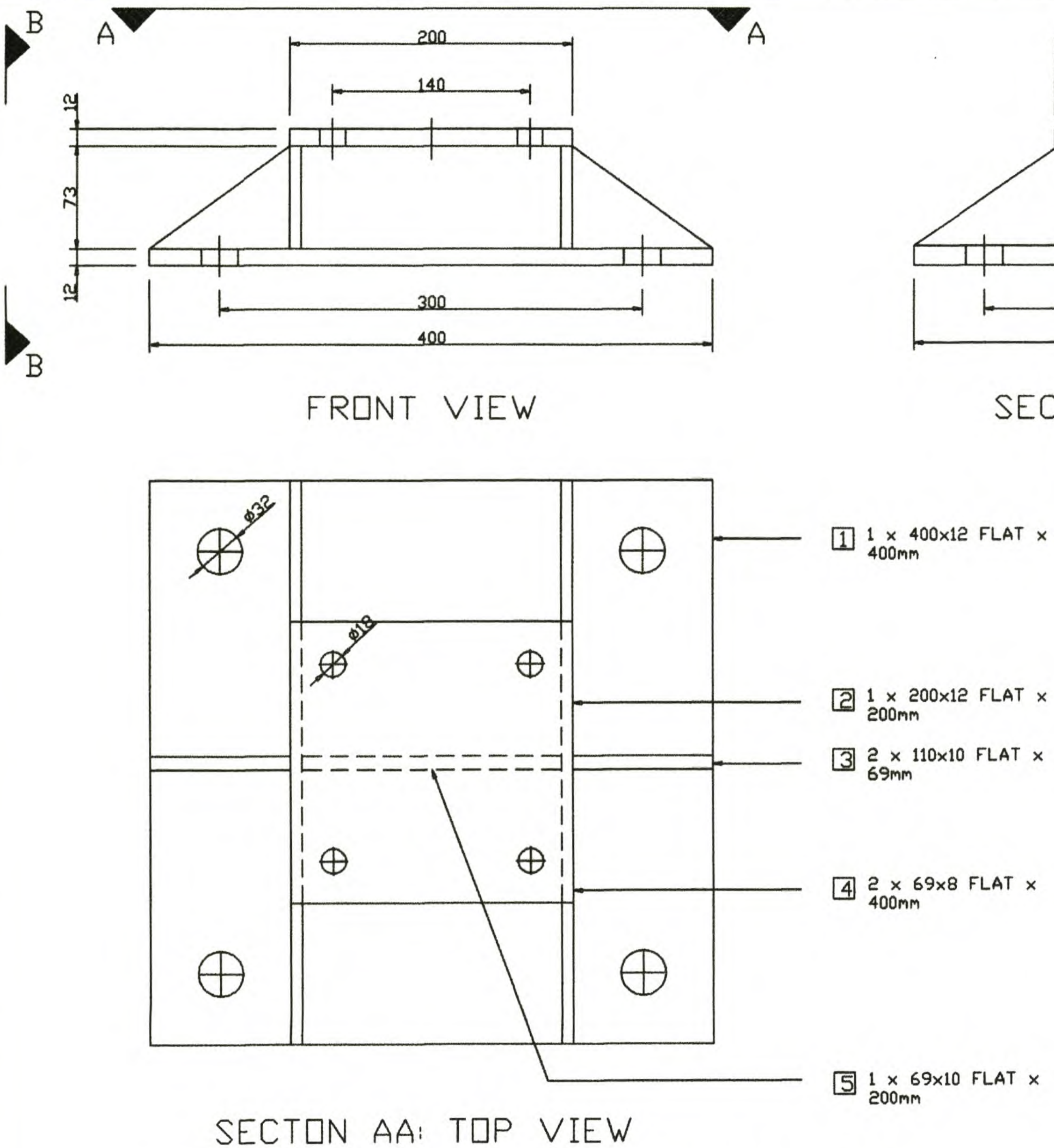
DESCRIPTION: TYPE B CONNECTOR
Drw. no.: 05-02/1

SCALE 1:5 UNLESS NOTED OTHERWISE

02/01/2001



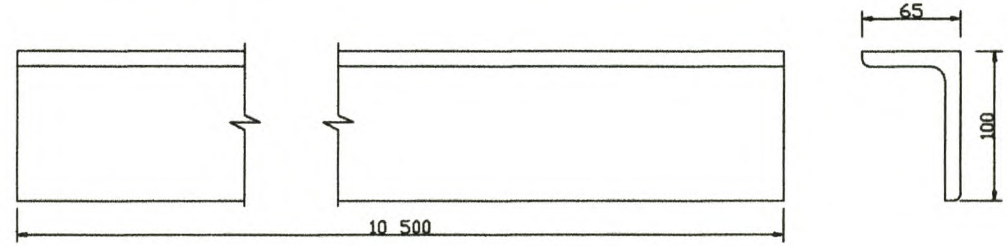
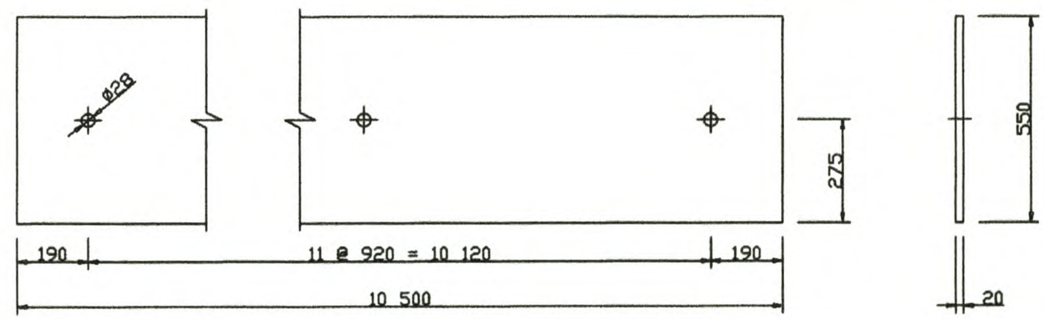
B
A
A
200
140
12
124
12
347
420
B
FRONT VIEW
200
140
148
130
250
SECTION BB: LEFT VIEW
420
ø26
ø18
250
1 1 x 250x12 FLAT x 420mm
2 1 x 200x12 FLAT x 200mm
3 2 x 124x10 FLAT x 110mm
4 2 x 124x8 FLAT x 250mm
5 1 x 124x10 FLAT x 200mm
SECTION AA: TOP VIEW
USE WITH LATERAL SUPPORTS AND SUPPORTS
4 TYPE C CONNECTORS AS DRAWN
DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS
DESCRIPTION: TYPE C CONNECTOR
DRW. NO.: 05-03/1
SCALE 1:5 UNLESS NOTED OTHERWISE
02/01/2001



USE WITH LATERAL SUPPORTS AND LOAD BRIDGES

6 TYPE D CONNECTORS AS DRAWN

DEVELOPMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS	
DESCRIPTION:	TYPE D CONNECTOR
DRW. NO.:	05-04/1
SCALE 1:5 UNLESS NOTED OTHERWISE	
	25/10/1999

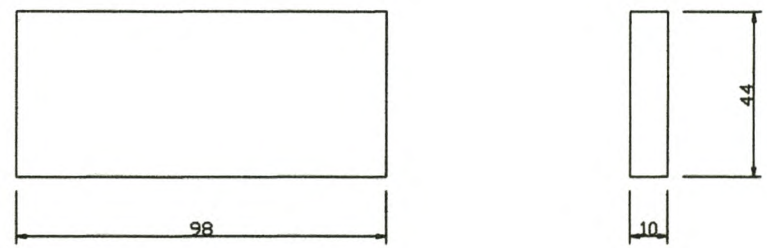
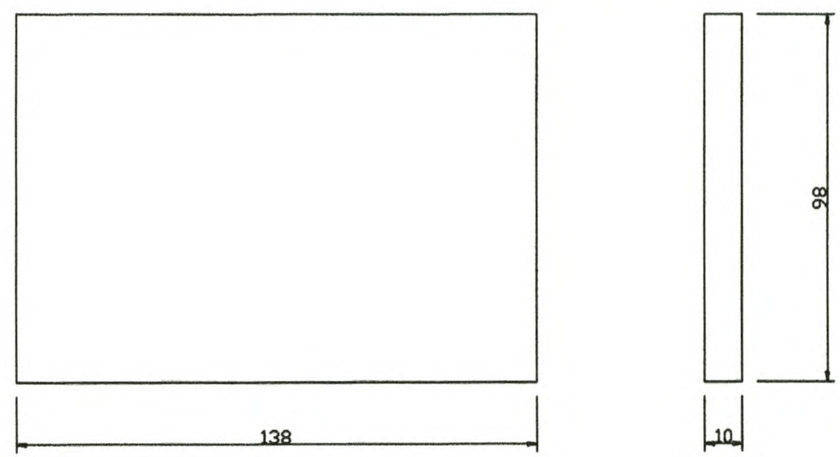
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
01-01 1	TRACK: ANGLES	100x65x10 ANGLE x10 500mm	8	
01-01 2	TRACK: BASE PLATE	550x20 FLAT x10 500mm	2	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TRACK WORKSHOP DETAIL
DRW. NO.: 01-WS-1

NOTE: NOT TO SCALE

2/12/2000

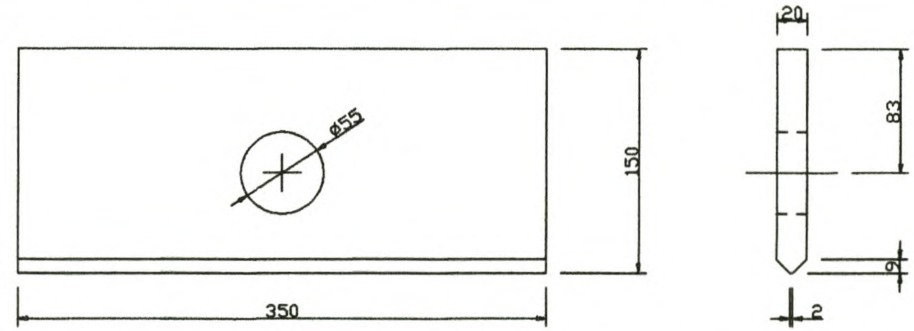
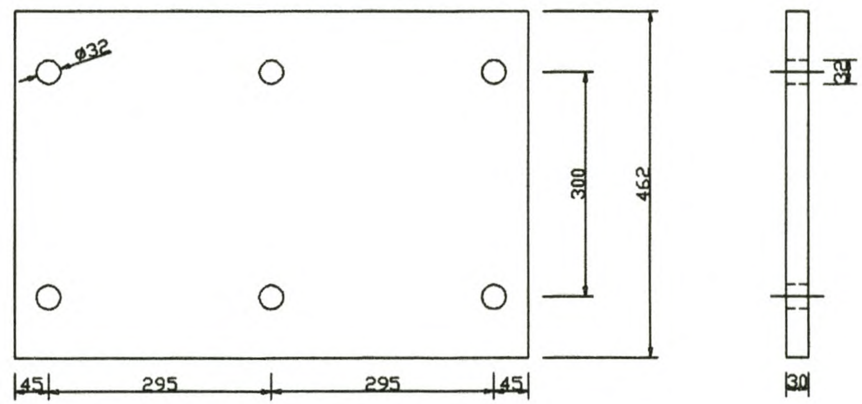
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
01-01 3	TRACK: WEB STIFFENERS	100 x 10 FLAT x 44 mm	96	
01-01 4	TRACK: WEB STIFFENERS	100 x 10 FLAT x 138 mm	96	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TRACK WORKSHOP DETAIL
DRW. NO.: 01-WS-2

NOTE: NOT TO SCALE

26/01/2000

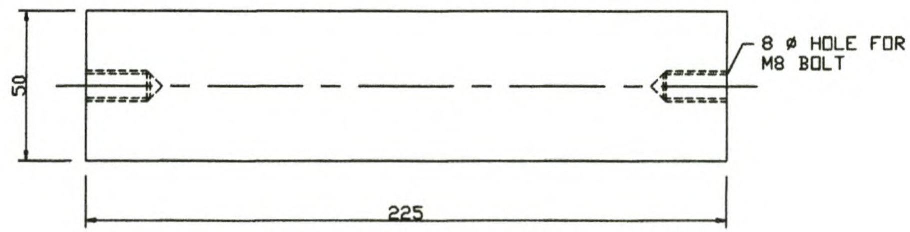
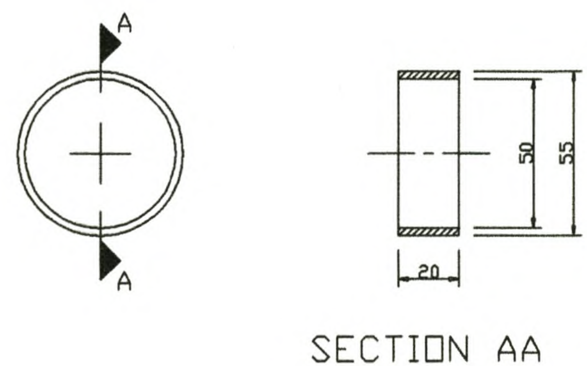
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
02-01 1	HINGE: WEB PLATES	150 x 20 FLAT x 350mm	24	
01-01 2	HINGE: BASE PLATE	500 x 30 FLAT x 680mm	6	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE WORKSHOP DETAIL
DRW. NO.: 02-WS-1

NOTE: NOT TO SCALE

26/10/1999

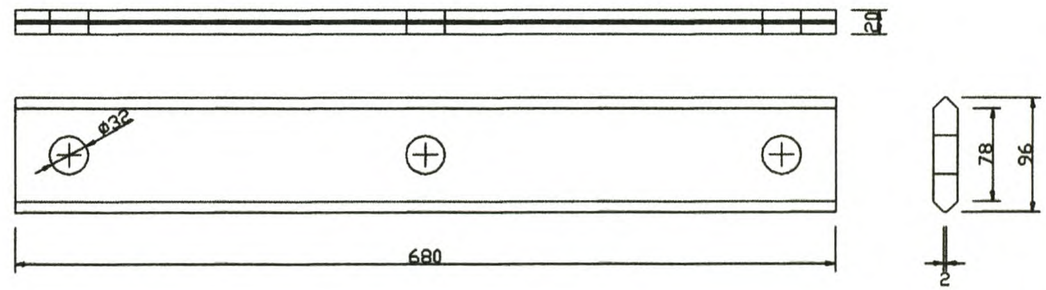
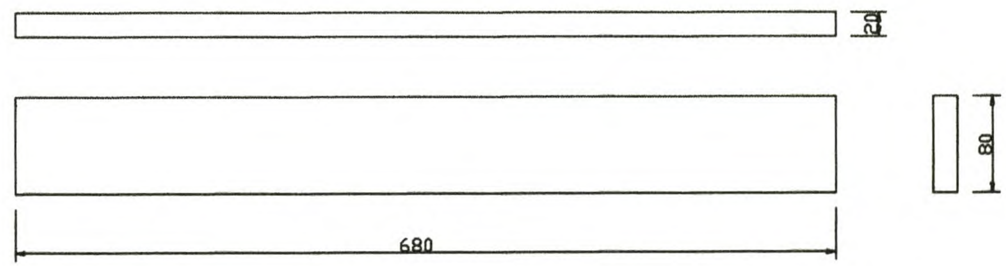
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
02-02 1	HINGE: PINS	50 ROUND x 225mm	12	
02-02 2	HINGE: 5020 P10 BUSHES	PAP 5020 P10	48	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE WORKSHOP DETAIL
DRW. NO.: 02-WS-2

NOTE: NOT TO SCALE

11/01/2000

MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
02-03 1	FIXING BRACKET: FLANGE	100 x 20 FLAT x 680mm	6	
02-03 2	FIXING BRACKET: WEB	80 x 20 FLAT x 680mm	12	

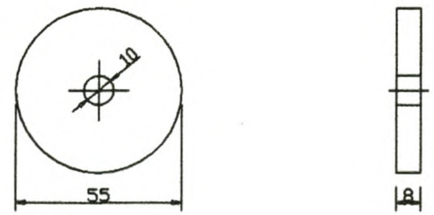
DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE WORKSHOP DETAIL

DRW. NO.: 02-WS-3

NOTE: NOT TO SCALE

26/10/1999

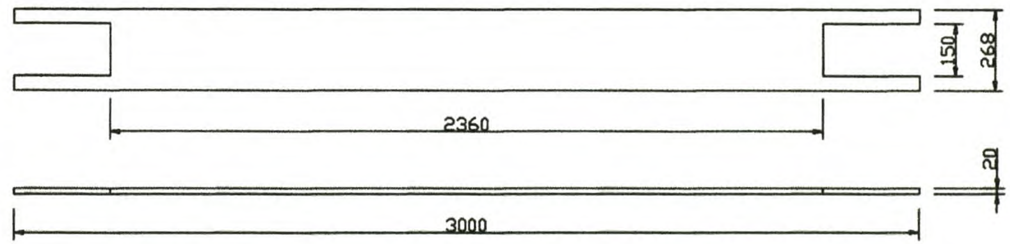
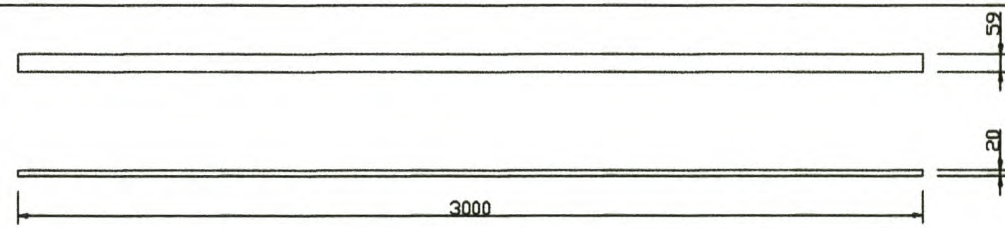
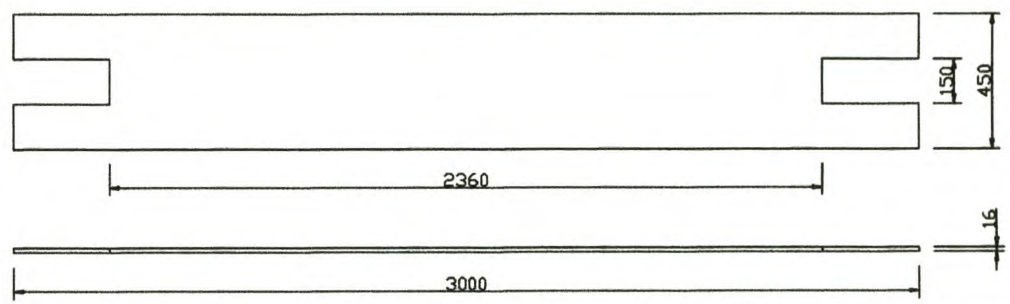
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
02-02 3	HINGE: PIN CAPS	55 ROUND x 8mm	24	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: HINGE WORKSHOP DETAIL
DRW. NO.: 02-WS-4

NOTE: NOT TO SCALE

11/01/2000

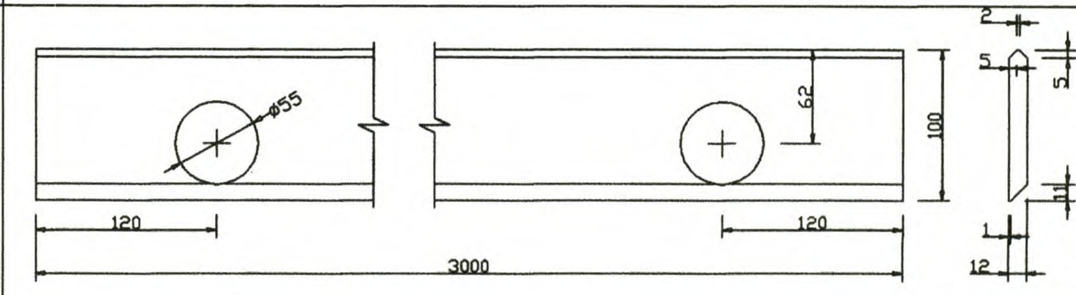
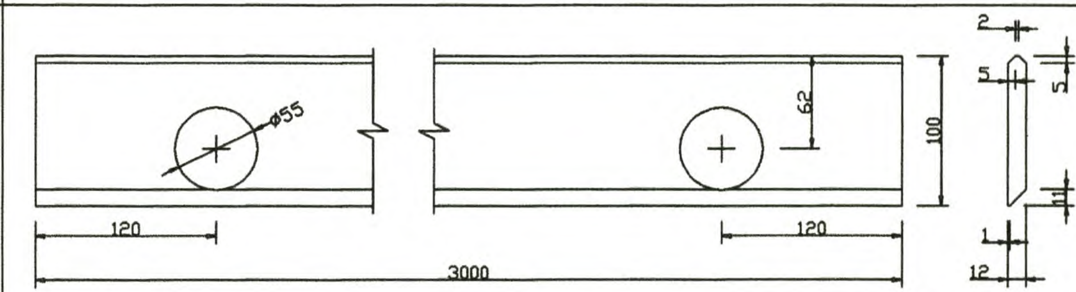
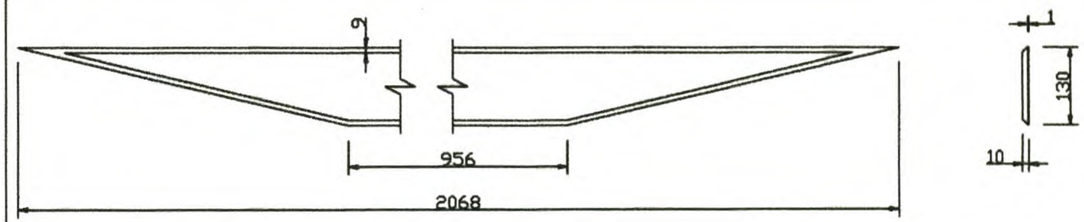
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-01 [1]	LOAD BRIDGE: FLANGE PLATE	300 x 20 FLAT x 3 000mm	1	
03-01 [2]	LOAD BRIDGE: FLANGE PLATE	60 x 20 FLAT x 3 000mm	2	
03-01 [5]	LOAD BRIDGE: FLANGE PLATE	450 x 16 FLAT x 3 000mm	1	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-1

NOTE: NOT TO SCALE

26/01/2000

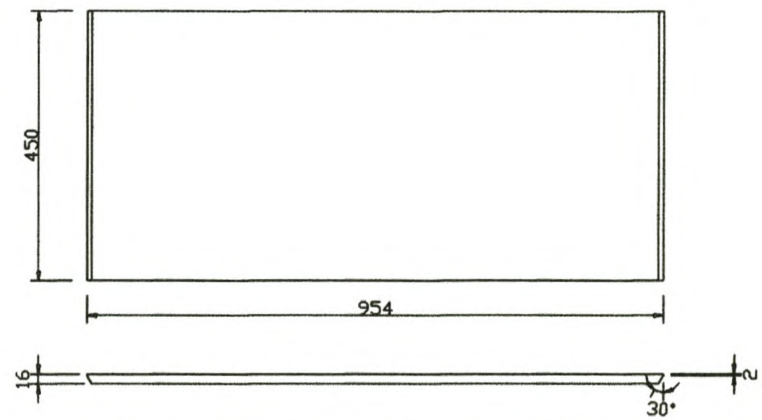
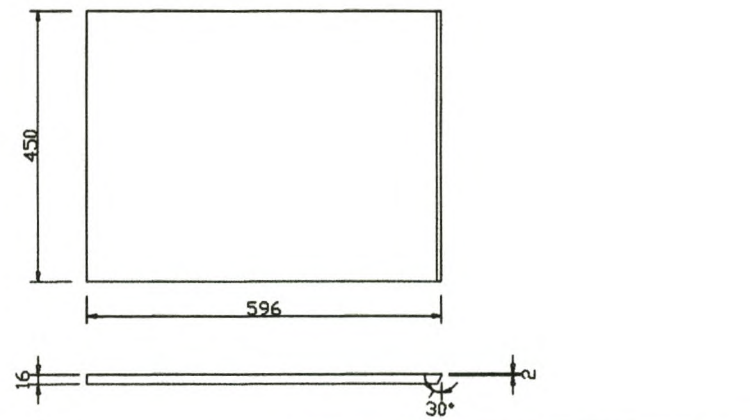
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-01 3	LOAD BRIDGE: WEB PLATES	100 x 12 FLAT x 3 000mm	2	
03-01 4	LOAD BRIDGE: WEB PLATES	100 x 12 FLAT x 3 000mm	2	
03-01 6	LOAD BRIDGE: WEB PLATES	130 x 10 FLAT x 2 068mm	2	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-2

NOTE: NOT TO SCALE

26/01/2000

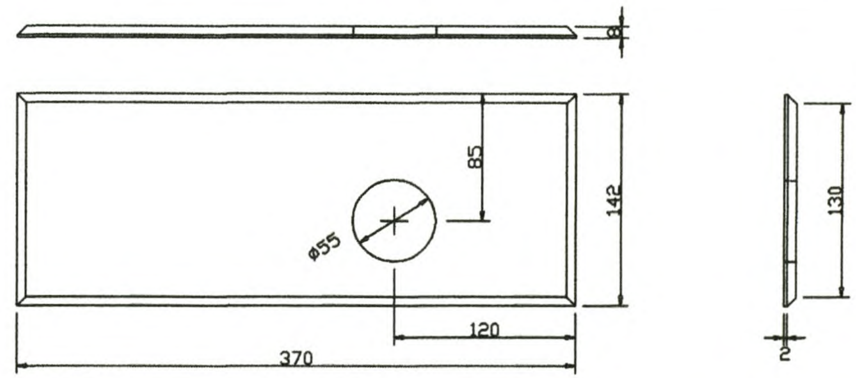
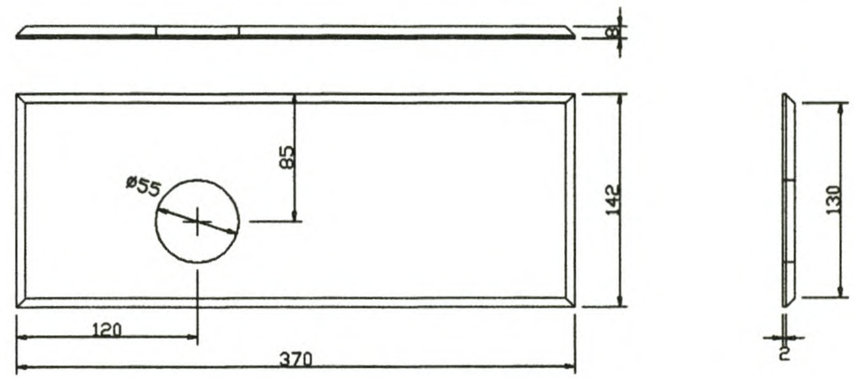
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-01 7	LOAD BRIDGE: FLANGE PLATES	450 x 16 FLAT x 954mm	1	
03-01 8	LOAD BRIDGE: FLANGE PLATES	450 x 16 FLAT x 596mm	2	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-3

NOTE: NOT TO SCALE

27/01/2000

MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-01 9	LOAD BRIDGE: HINGE PLATES	150 x 8 FLAT x 370mm	2	
03-01 9X	LOAD BRIDGE: HINGE PLATES	150 x 8 FLAT x 370mm	2	

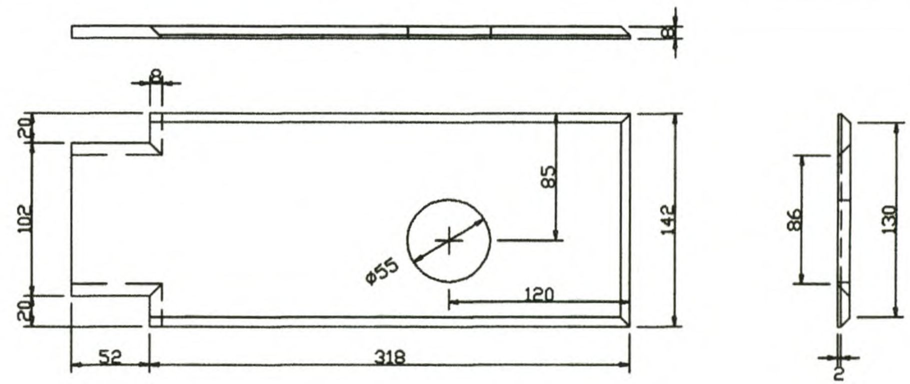
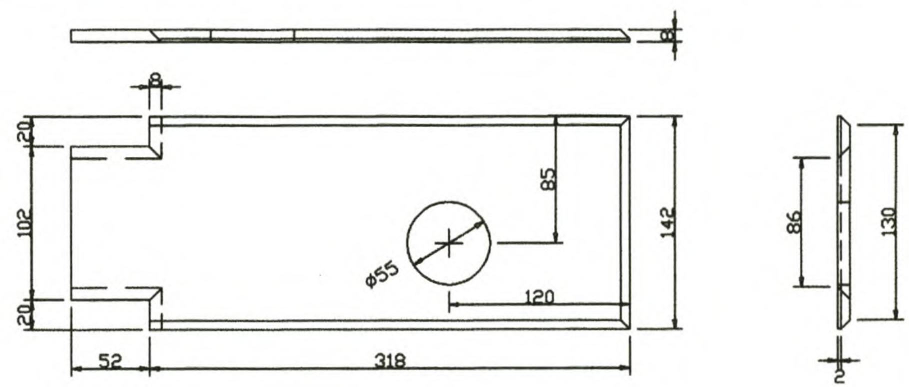
DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL

DRW. NO.: 03-WS-4

NOTE: NOT TO SCALE

27/01/2000

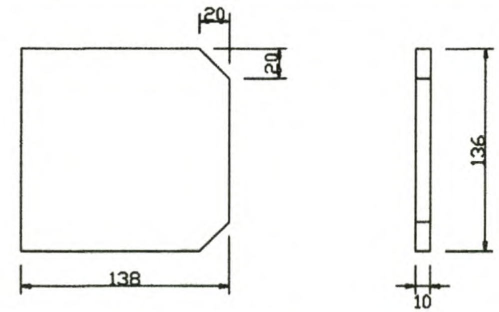
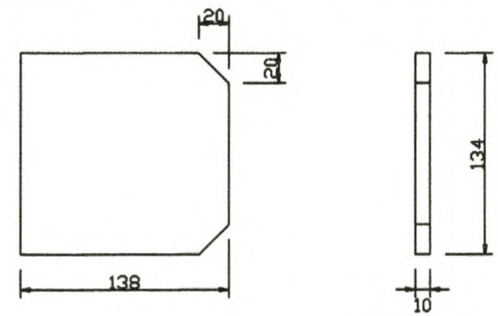
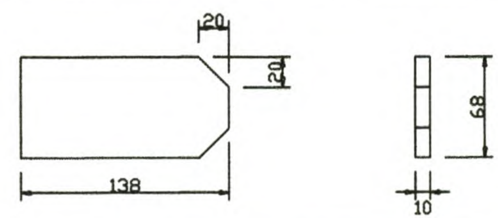
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-01 10	LOAD BRIDGE: HINGE PLATES	150 x 8 FLAT x 370mm	2	
03-01 10X	LOAD BRIDGE: HINGE PLATES	150 x 8 FLAT x 370mm	2	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-5

NOTE: NOT TO SCALE

27/01/2000

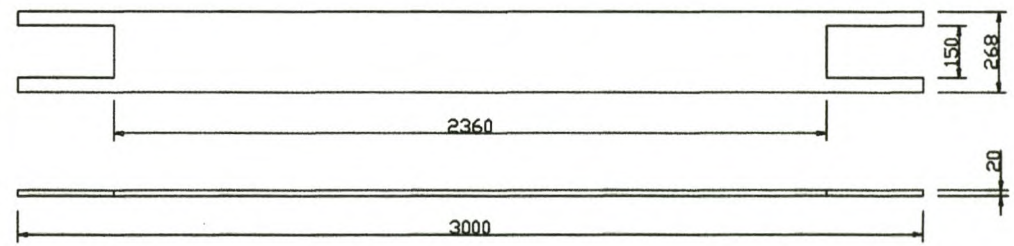
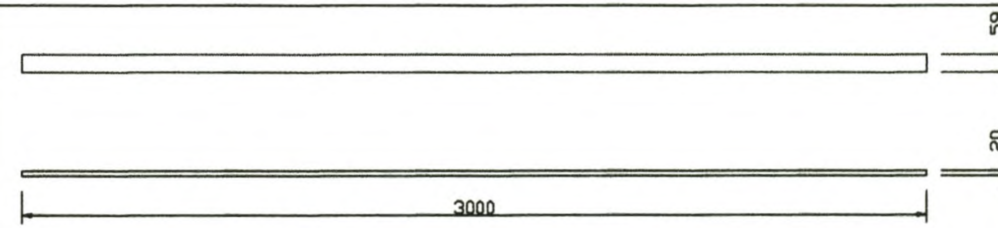
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-01 11	LOAD BRIDGE: WEB STIFFENERS	150 x 10 FLAT x 136mm	4	
03-01 12	LOAD BRIDGE: WEB STIFFENERS	150 x 10 FLAT x 134mm	4	
03-01 13	LOAD BRIDGE: WEB STIFFENERS	150 x 10 FLAT x 68mm	4	

DEVELOPEMENT OF A MULTIPURPOSE
BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-6

NOTE: NOT TO SCALE

27/01/2000

<table>
<tr><th>MARK</th><th>DESCRIPTION</th><th>MATERIAL</th><th>QTY</th><th>DIMENSIONS</th></tr>
<tr><td>03-02 [1]</td><td>LOAD BRIDGE: FLANGE PLATE</td><td>300 x 20 FLAT x 3 000mm</td><td>2</td><td>
</td></tr>
<tr><td>03-02 [2]</td><td>LOAD BRIDGE: FLANGE PLATE</td><td>60 x 20 FLAT x 3 000mm</td><td>4</td><td>
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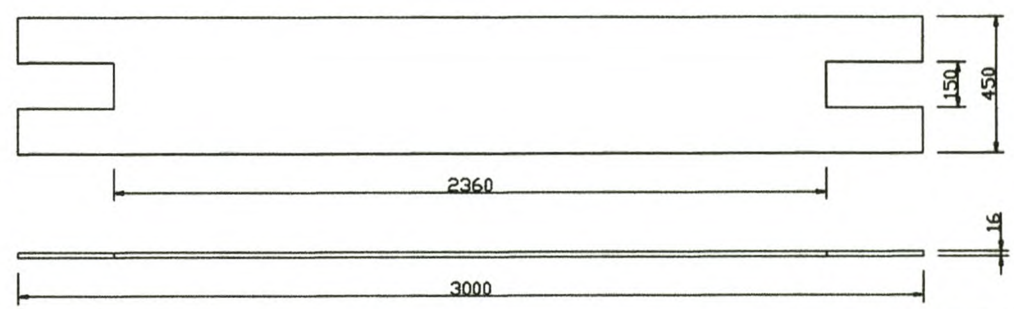
<tr><td>03-02 [5]</td><td>LOAD BRIDGE: FLANGE PLATE</td><td>450 x 16 FLAT x 3 000mm</td><td>2</td><td>
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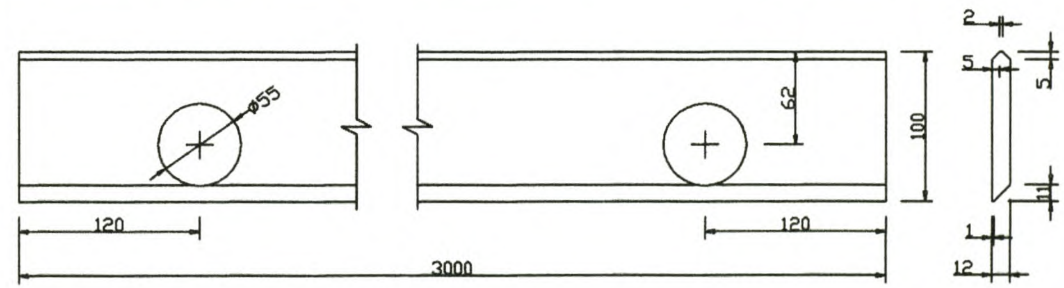
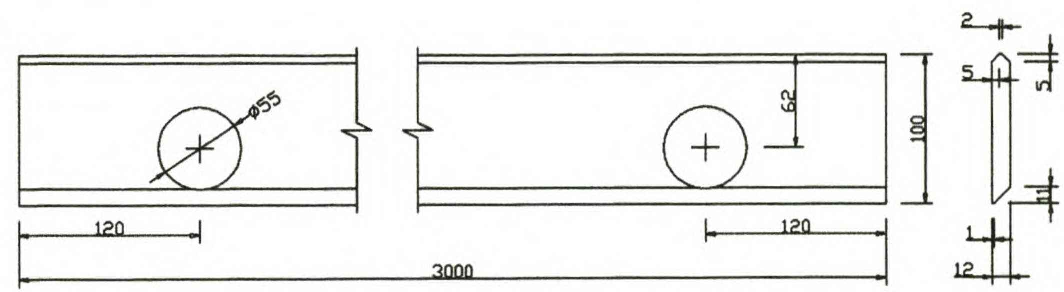
DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL

DRW. NO.: 03-WS-7

NOTE: NOT TO SCALE

27/01/2000

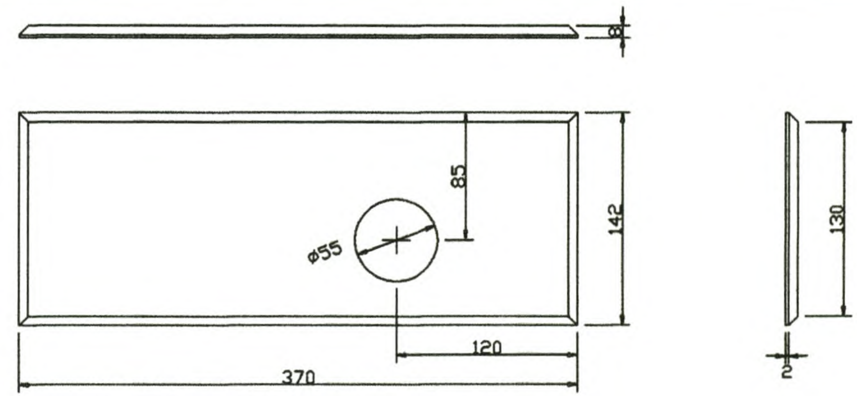
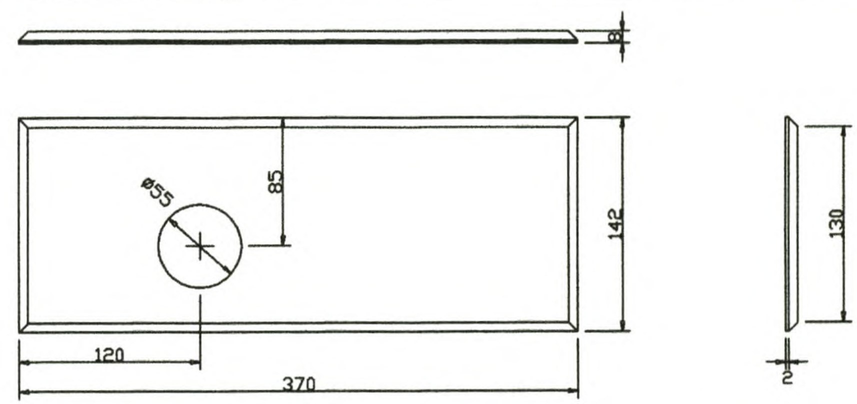
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-02 3	LOAD BRIDGE: WEB PLATES	100 x 12 FLAT x 3 000mm	4	
03-02 4	LOAD BRIDGE: WEB PLATES	100 x 12 FLAT x 3 000mm	4	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-8

NOTE: NOT TO SCALE

28/01/2000

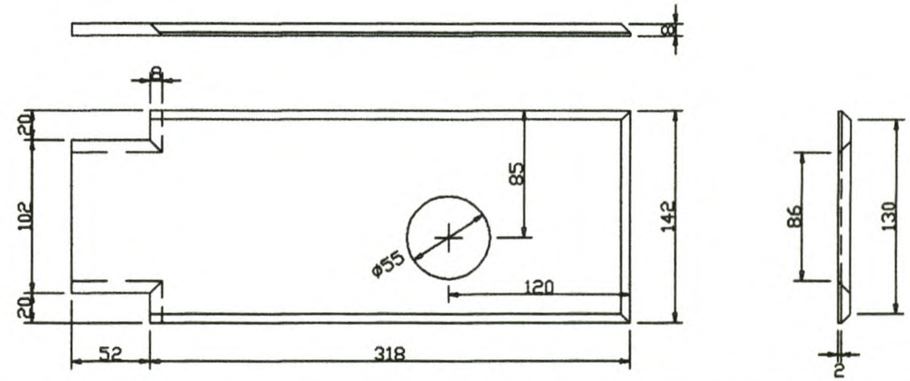
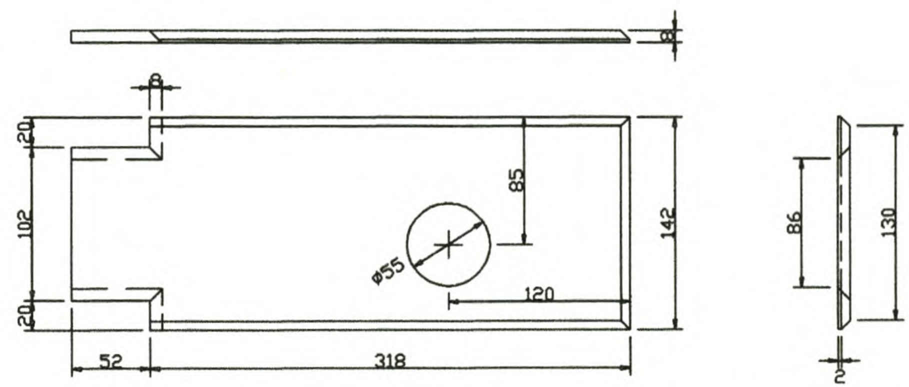
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-02 9	LOAD BRIDGE: HINGE PLATES	150 x 8 FLAT x 370mm	4	
03-02 9X	LOAD BRIDGE: HINGE PLATES	150 x 8 FLAT x 370mm	4	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-9

NOTE: NOT TO SCALE

03/02/2000

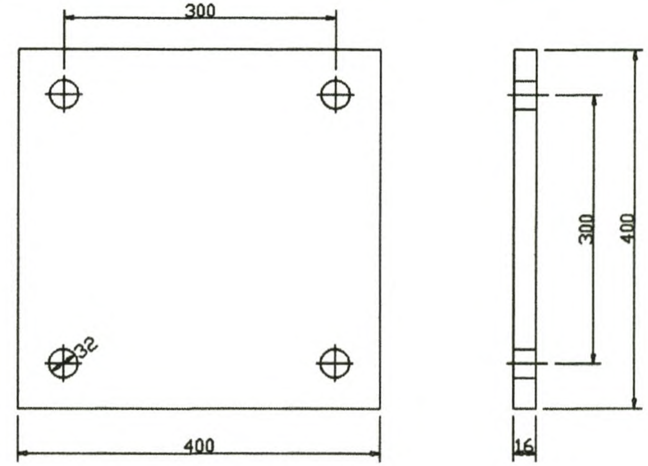
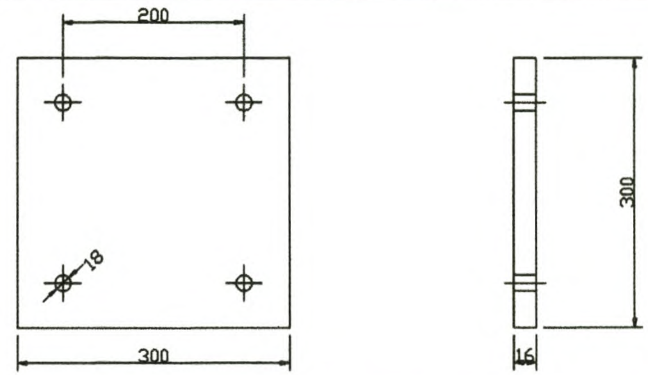
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-02 10	LOAD BRIDGE: HINGE PLATES	150 x 8 FLAT x 370mm	4	
03-02 10X	LOAD BRIDGE: HINGE PLATES	150 x 8 FLAT x 370mm	4	

DEVELOPEMENT OF A MULTIPURPOSE
BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-10

NOTE: NOT TO SCALE

26/10/1999

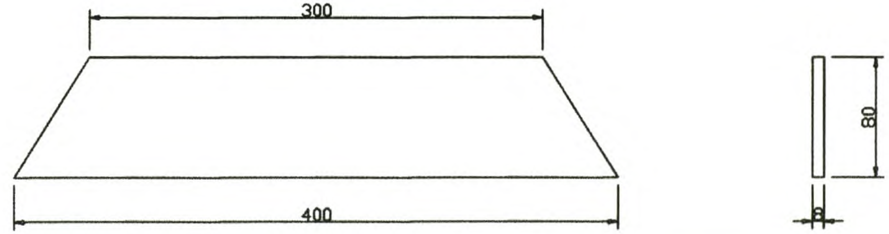
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-03 1	CONNECTOR: BASE PLATE	400 x 16 FLAT x 400mm	4	
03-03 2	CONNECTOR: BASE PLATE	300 x 16 FLAT x 300mm	4	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-11

NOTE: NOT TO SCALE

26/10/1999

MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
03-03 3	CONNECTOR: WEB PLATE	80 x 8 FLAT x 400mm	8	
03-03 5	CONNECTOR: WEB PLATE	80 x 8 FLAT x 146mm	16	
03-03 4	CONNECTOR: WEB PLATE	80 x 8 FLAT x 92mm	8	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

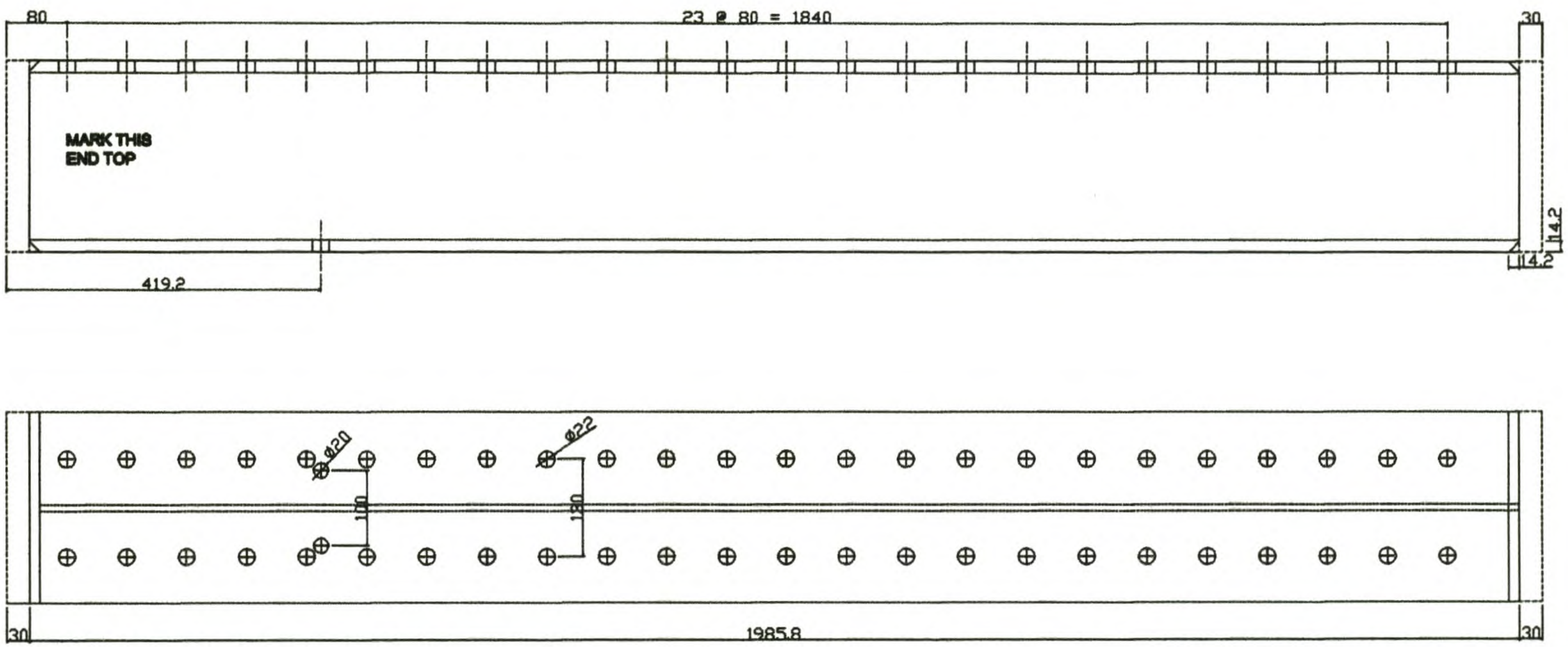
DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 03-WS-12

NOTE: NOT TO SCALE

26/10/1999

MARK	DESCRIPTION	MATERIAL	QTY
04-01 [1]	Support Column	254 x 254 x 73 H x1 985.8mm	2

DIMENSIONS



Development of a Multipurpose Beam Testing Apparatus

DESCRIPTION: VERTICAL SUPPORT WORKSHOP DETAILS

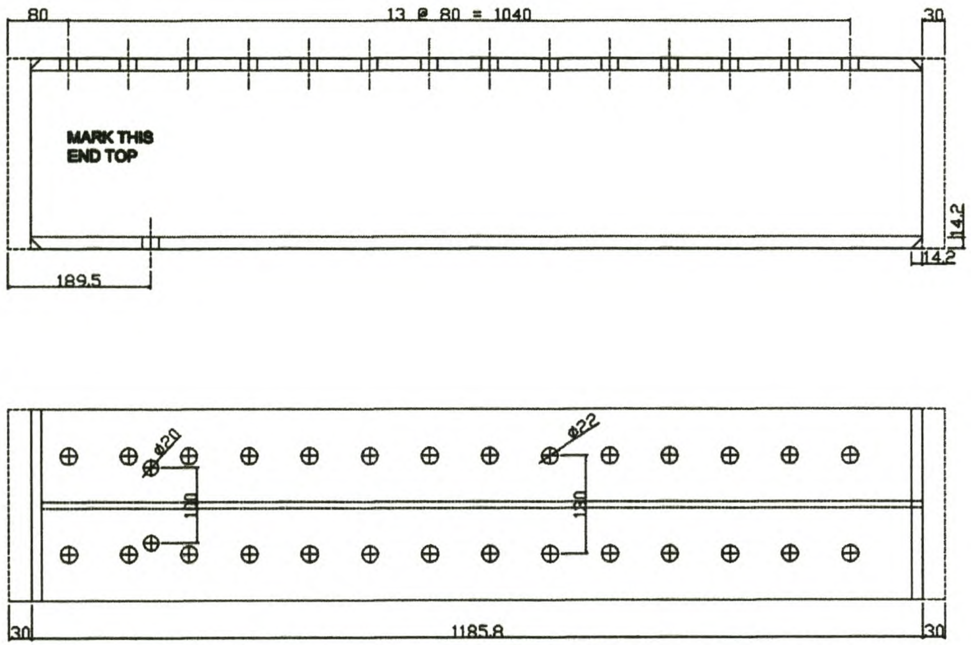
DRW. NO.: 04-WS-1

NOTE: NOT TO SCALE

05/10/2000

MARK	DESCRIPTION	MATERIAL	QTY
04-01 $\boxed{2}$	Support Column	254 x 254 x 73 H x1 185.8mm	2

DIMENSIONS



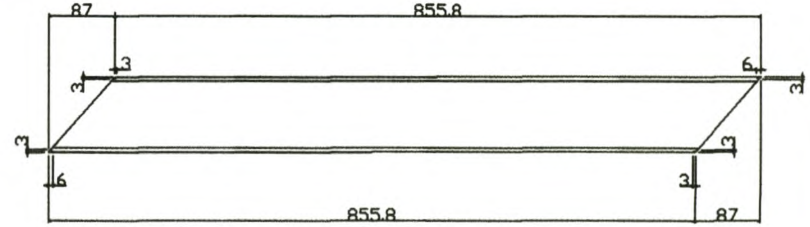
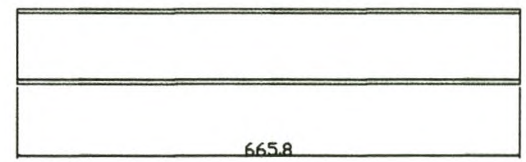
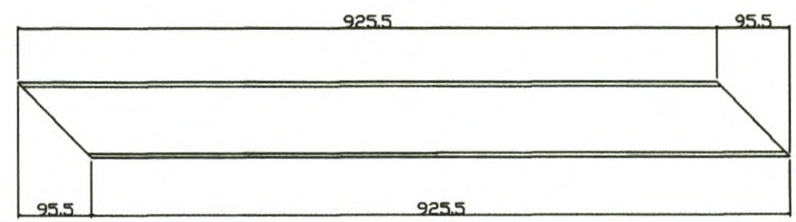
Development of a Multipurpose Beam Testing Apparatus

DESCRIPTION: VERTICAL SUPPORT WORKSHOP DETAILS

DRW. NO.: 04-WS-2

NOTE: NOT TO SCALE

05/10/2000

Mark	Description	Material	Qty	Dimensions
04-01 3	Support Brace	IPE 100 x 942.5 mm	1	
04-01 4	Support Brace	IPE 100 x 665.8 mm	2	
04-01 5	Support Brace	IPE 100 x 1021 mm	1	

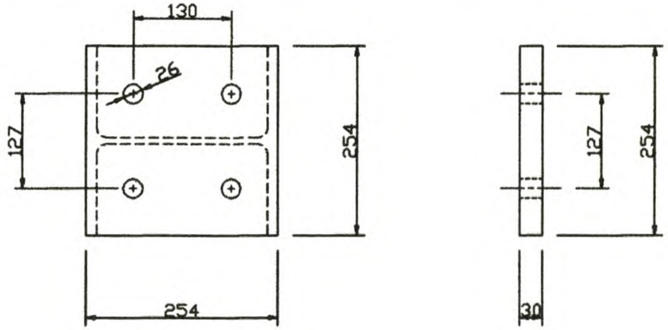
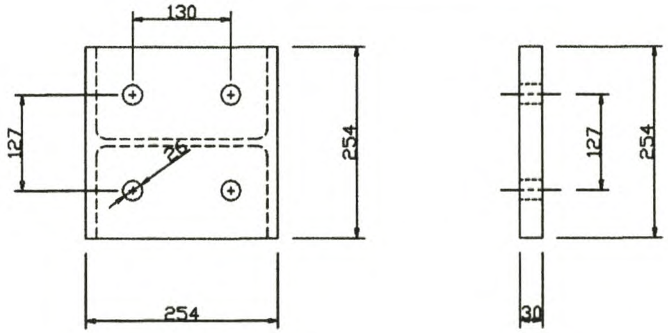
Development of a Multipurpose Beam Testing Apparatus

DESCRIPTION: VERTICAL SUPPORT WORKSHOP DETAILS

DRW. NO.: 04-WS-3

NOTE: NOT TO SCALE

20/10/2002

Mark	Description	Material	Qty	Dimensions
04-01 6	Support Cap Plt	254 x 10 Flat x254mm	2	
04-01 7	Support Base Plt	254 x 10 Flat x254mm	2	

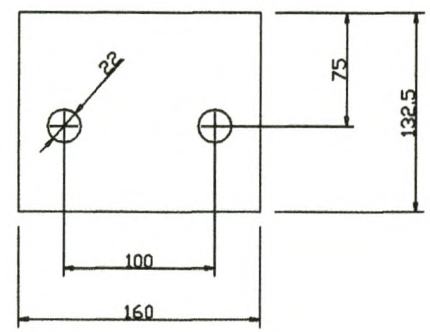
Development of a Multipurpose Beam Testing Apparatus

DESCRIPTION: VERTICAL SUPPORT WORKSHOP DETAILS

DRW. NO.: 04-WS-4

NOTE: NOT TO SCALE

26/10/1999

Mark	Description	Material	Qty	Dimensions
04-01 8	Brace End Plt	160 x 10 Flat x132.5 mm	2	

Development of a Multipurpose Beam Testing Apparatus

DESCRIPTION: VERTICAL SUPPORT WORKSHOP DETAILS

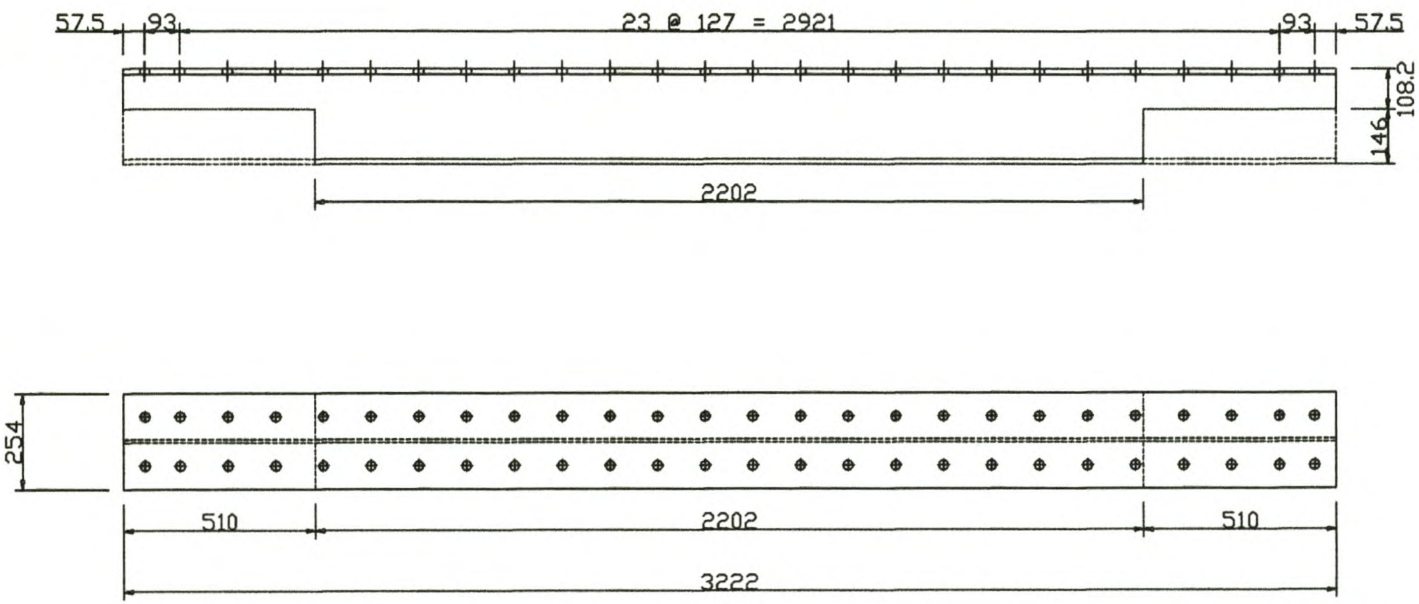
DRW. NO.: 04-WS-5

NOTE: NOT TO SCALE

20/10/2002

MARK	DESCRIPTION	MATERIAL	QTY
04-02 [1]	Support Beam	254 x 254 x 73 H x3 222mm	2

DIMENSIONS



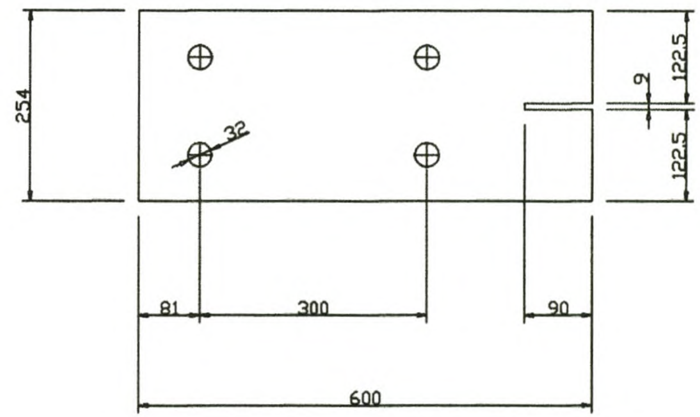
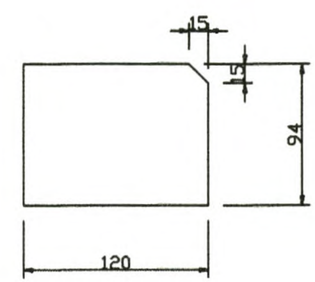
Development of a Multipurpose Beam Testing Apparatus

DESCRIPTION: SUPPORT BRIDGE WORKSHOP DETAILS

DRW. NO.: 04-WS-6

NOTE: NOT TO SCALE

05/10/2000

Mark	Description	Material	Qty	Dimensions
04-02 [2]	Support Plt	254 x 20 Flat x600 mm	4	
04-02 [3]	Web Stiffener	120 x 8 Flat x94 mm	12	

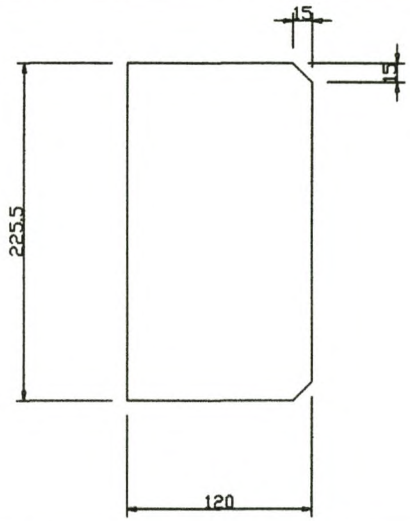
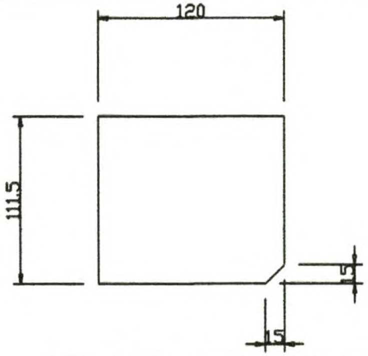
Development of a Multipurpose Beam Testing Apparatus

DESCRIPTION: SUPPORT BRIDGE WORKSHOP DETAILS

DRW. NO.: 04-WS-7

NOTE: NOT TO SCALE

26/10/1999

Mark	Description	Material	Qty	Dimensions
04-02 4	Web Stiffener	120 x 8 Flat x225.5 mm	18	
04-02 5	Web Stiffener	120 x 8 Flat x111.5 mm	4	

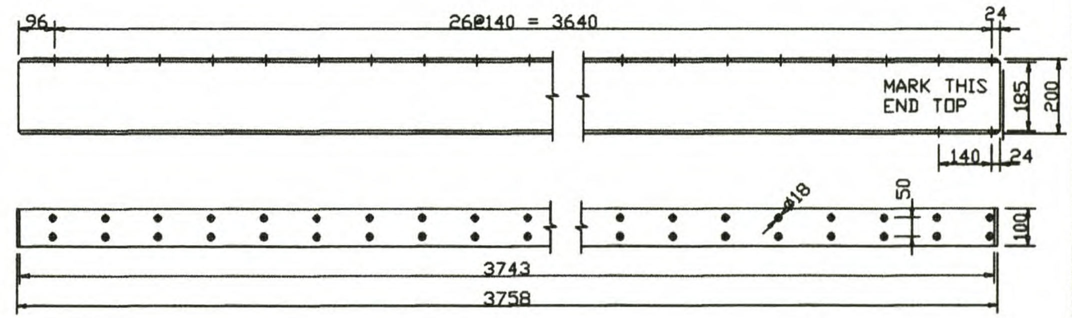
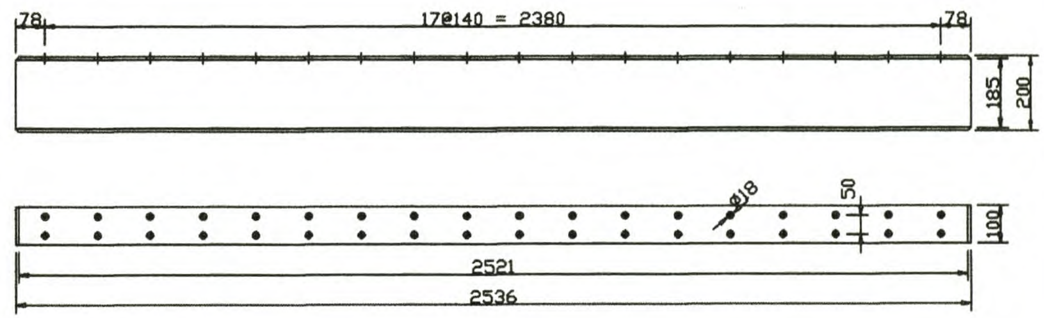
Development of a Multipurpose Beam Testing Apparatus

DESCRIPTION: SUPPORT BRIDGE
WORKSHOP DETAILS

DRW. NO.: 04-WS-8

NOTE: NOT TO SCALE

26/10/1999

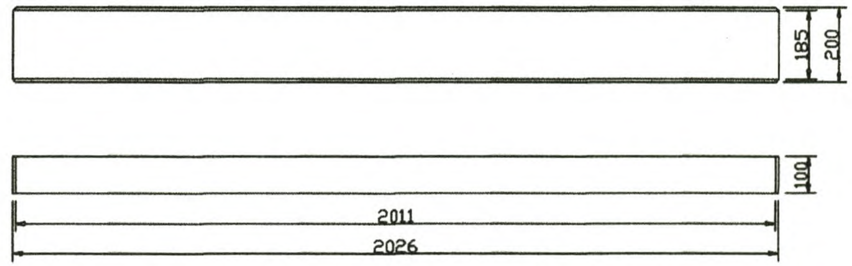
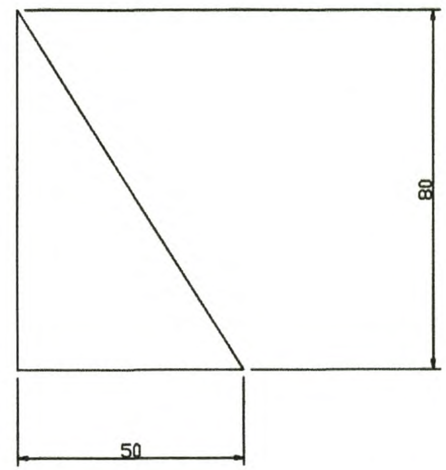
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-01 $\boxed{1}$	LATERAL FRAME: COLUMN	IPE 200 x 3 758mm	10	
05-01 $\boxed{2}$	LATERAL FRAME: BEAM	IPE 200 x 2 536mm	5	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: LATERAL FRAME
DRW. NO.: 05-WS-1

NOTE: NOT TO SCALE

26/10/1999

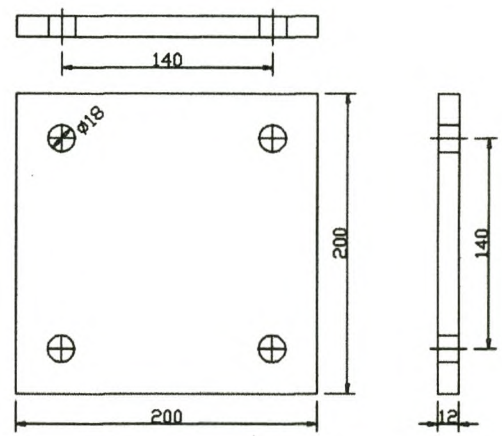
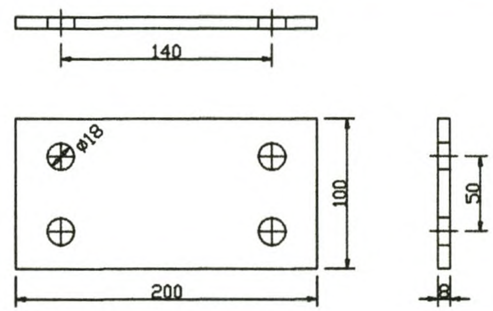
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-01 3	LATERAL FRAME: BEAM	IPE 200 x 2 026mm	5	
05-01 8	LATERAL FRAME: STIFFENER	50x8 FLAT x 80mm	40	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: LATERAL FRAME
DRW. NO.: 05-WS-2

NOTE: NOT TO SCALE

26/10/1999

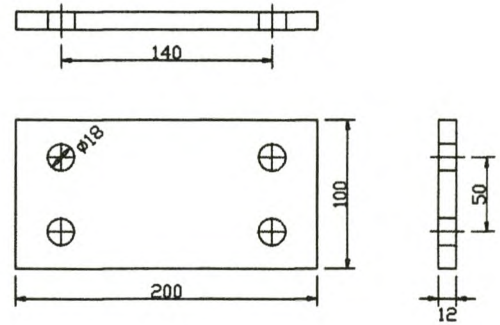
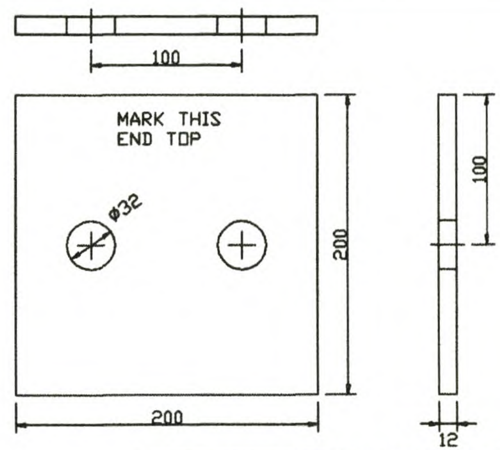
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-01 4	LATERAL FRAME: BASE PLATE	100 x 12 FLAT x 200mm	10	
05-01 5	LATERAL FRAME: END PLATE	100 x 8 FLAT x 200mm	10	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: LATERAL FRAME
DRW. NO.: 05-WS-3

NOTE: NOT TO SCALE

26/10/1999

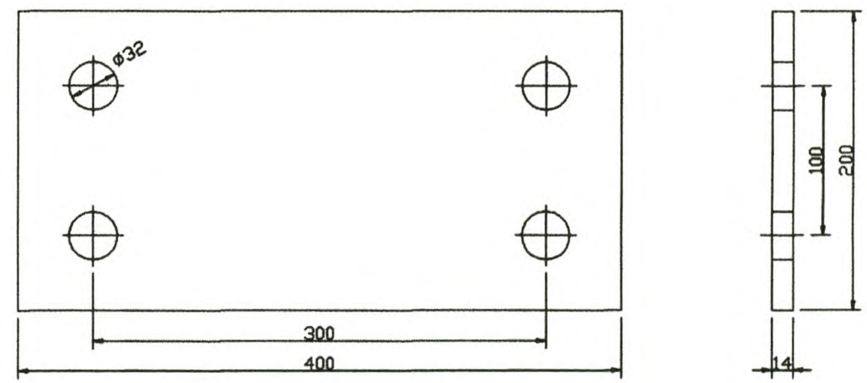
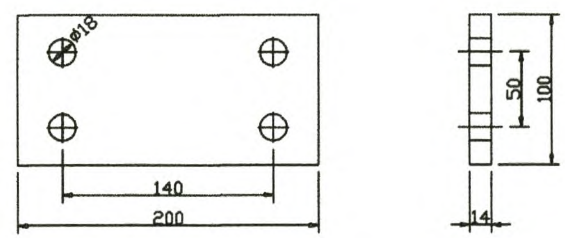
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-01 6	LATERAL FRAME: END PLATE	100 x 12 FLAT x 200mm	15	
05-01 7	LATERAL FRAME: END PLATE	200 x 12 FLAT x 200mm	5	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: LATERAL FRAME
DRW. NO.: 05-WS-4

NOTE: NOT TO SCALE

26/10/1999

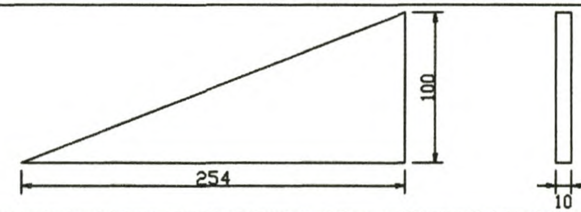
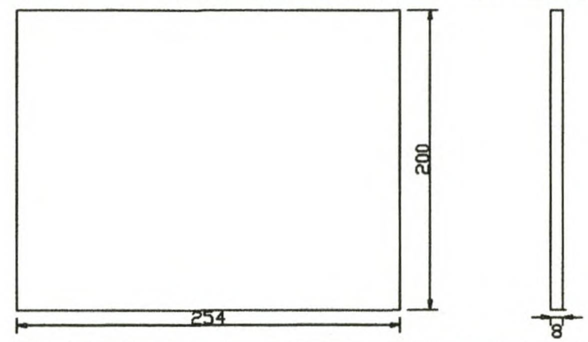
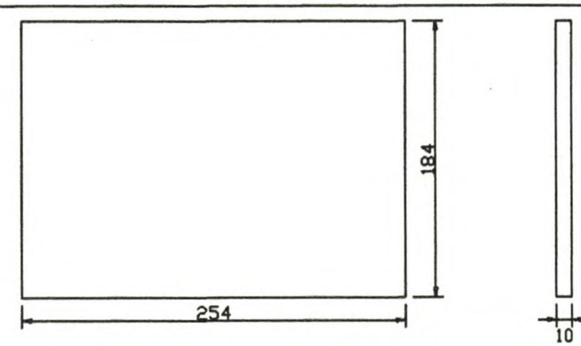
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-02 1	CONNECTOR: BASE PLATE	200 x 14 FLAT x 400mm	6	
05-02 2	CONNECTOR: BASE PLATE	200 x 14 FLAT x 100mm	6	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TYPE B CONNECTOR
DRW. NO.: 05-WS-5

NOTE: NOT TO SCALE

26/10/1999

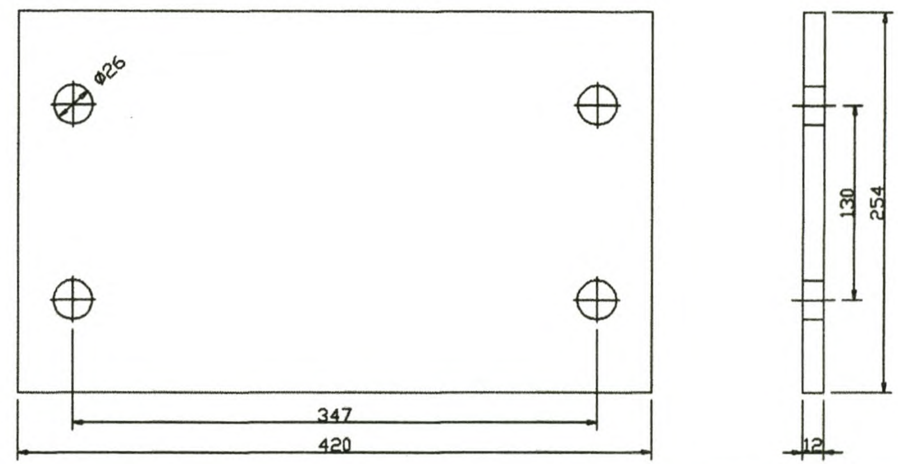
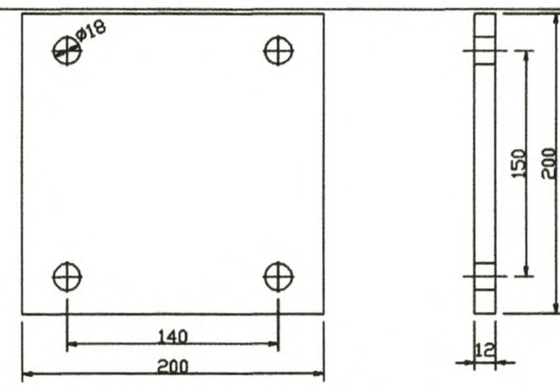
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-02 $\boxed{3}$	CONNECTOR: WEB PLATE	100 x 10 FLAT x 254mm	12	
05-02 $\boxed{4}$	CONNECTOR: WEB PLATE	200 x 8 FLAT x 254mm	12	
05-02 $\boxed{5}$	CONNECTOR: WEB PLATE	200 x 10 FLAT x 254mm	6	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TYPE B CONNECTOR
DRW. NO.: 05-WS-6

NOTE: NOT TO SCALE

26/10/1999

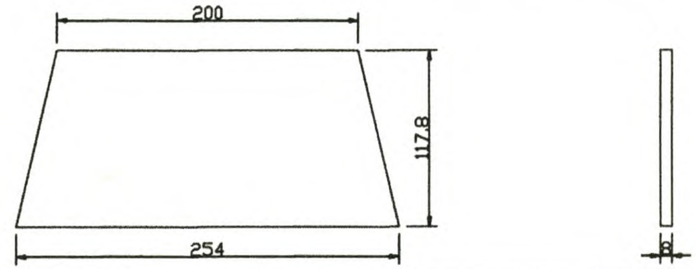
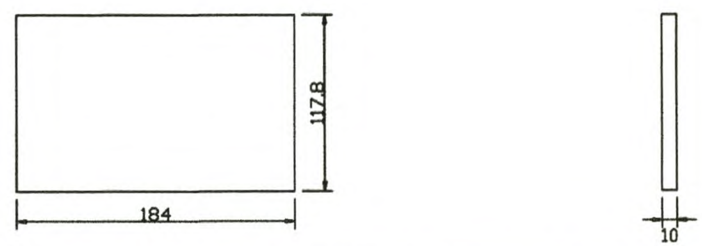
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-03 1	CONNECTOR: BASE PLATE	260 x 12 x 420mm	4	
05-03 2	CONNECTOR: BASE PLATE	200 x 12 FLAT x 200mm	4	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: BRIDGE WORKSHOP DETAIL
DRW. NO.: 05-WS-7

NOTE: NOT TO SCALE

26/10/1999

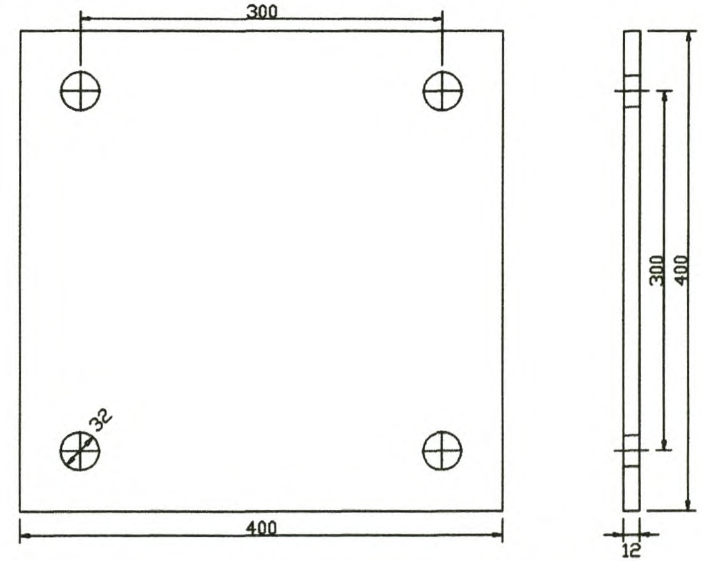
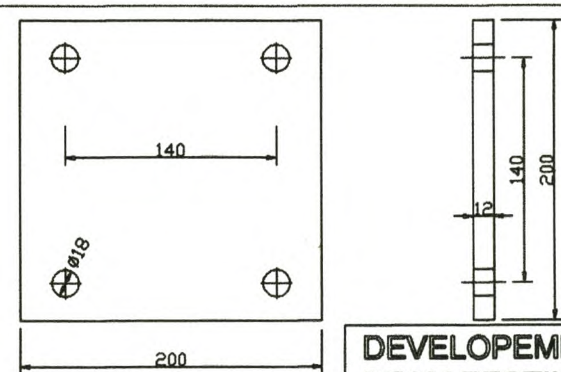
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-03 3	CONNECTOR: WEB PLATE	110 x 10 FLAT x 117.8mm	8	
05-03 4	CONNECTOR: WEB PLATE	130 x 8 FLAT x 254mm	8	
05-03 5	CONNECTOR: WEB PLATE	200 x 10 FLAT x 177.8mm	4	

DEVELOPEMENT OF A MULTIPURPOSE
BEAM TESTING APPARATUS

DESCRIPTION: TYPE C CONNECTOR
DRW. NO.: 05-WS-8

NOTE: NOT TO SCALE

26/10/1999

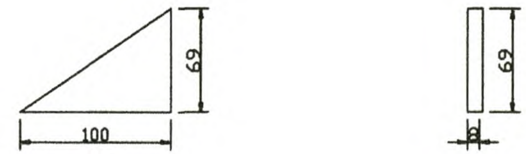
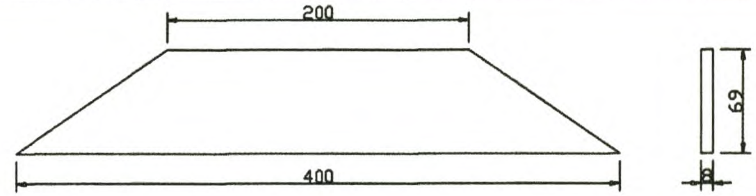
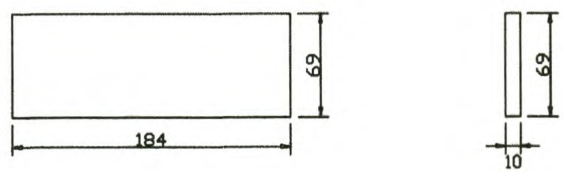
MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-04 [1]	CONNECTOR: BASE PLATE	400 x 12 x 400mm	6	
05-04 [2]	CONNECTOR: BASE PLATE	200 x 12 FLAT x 200mm	6	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TYPE D CONNECTOR
DRW. NO.: 05-WS-9

NOTE: NOT TO SCALE

26/10/1999

MARK	DESCRIPTION	MATERIAL	QTY	DIMENSIONS
05-04 3	CONNECTOR: WEB PLATE	100 x 10 FLAT x 69mm	12	
05-04 4	CONNECTOR: WEB PLATE	70 x 8 FLAT x 400mm	12	
05-04 5	CONNECTOR: WEB PLATE	100 x 10 FLAT x 184mm	6	

DEVELOPEMENT OF A MULTIPURPOSE BEAM TESTING APPARATUS

DESCRIPTION: TYPE D CONNECTOR
DRW. NO.: 05-WS-10

NOTE: NOT TO SCALE

26/10/1999

APPENDIX B

B.1. Deflection Evaluation of Steel Trusses

B.1.1. Test Sample Information

For more information on the design and detail drawings of the test samples, refer to Appendix A of 'Verplasing van Staal Vakwerke' by J. Neveling, February 2001, Department of Civil Engineering, University of Stellenbosch [22].

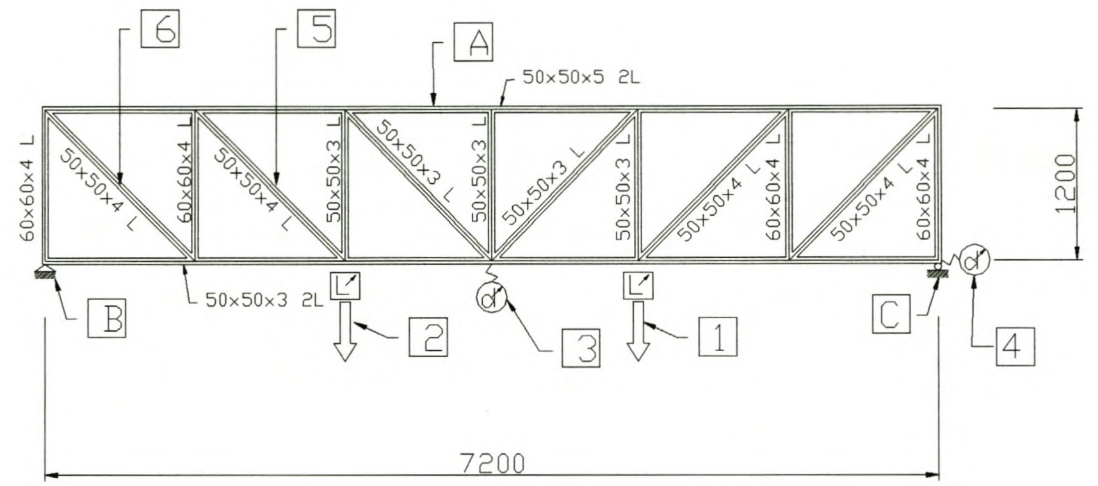
B.1.2. Test Arrangement

The test arrangement is described in chapter 6 and in 'Verplasing van Staal Vakwerke' by J. Neveling, February 2001, Department of Civil Engineering, University of Stellenbosch [22].

B.1.3. Test Data

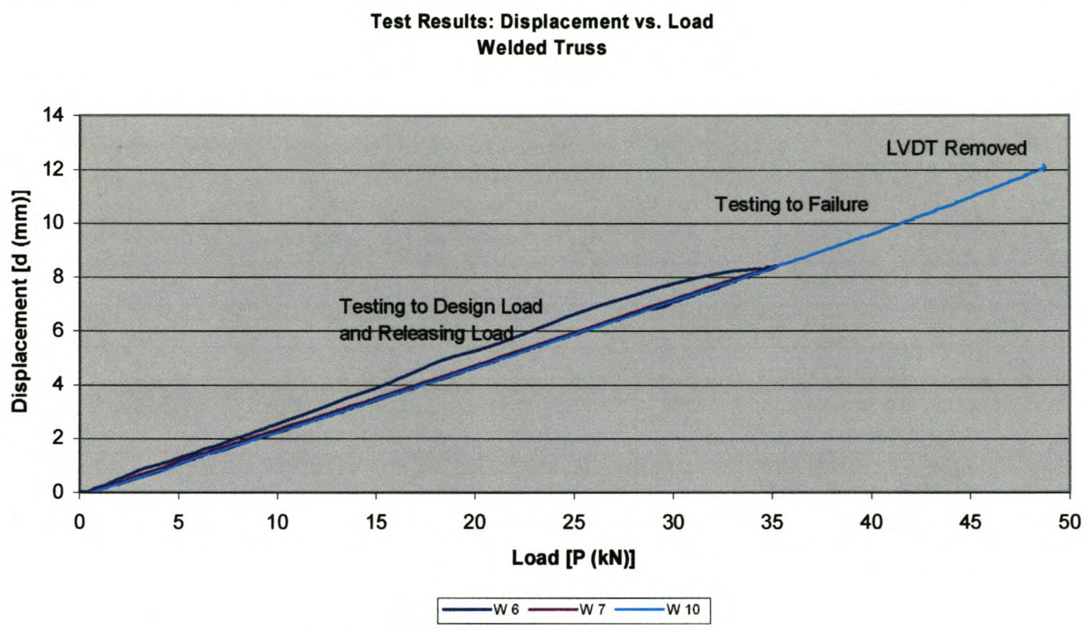
The truss layout with the positions of the measuring equipment is indicated in Figure B.1.

The calibrated test data for the following tests is attached and a summary thereof is plotted in FIGURE B.2.



Test Layout:	
A. Truss B. Pinned Support	C. Roller Support
Measurement Data:	
1. Load Cell: Force Measured 2. Load Cell: Force Measured 3. LVDT: Vertical Displacement Measured	4. LVDT: Horizontal Displacement Measured 5. Strain Gauges: Strain Measured 6. Strain Gauges: Strain Measured

Figure B.1 Truss Set



Test Number	Test Description
W6	Welded Truss: Loaded to design load, Load released
W7	Welded Truss: Loaded to design load, Load released
W10	Welded Truss: Loaded to failure

Figure B.2 Summary of Test Data

APPENDIX C

The MTA was designed in accordance with SABS 162: 1- 1993 The Structural use of Steel Part 1: Limit-States Design of Hot-Rolled Steelwork [2] and Structural Steelwork Connections (Limit States Design) [29]. The Southern African Structural Steelwork Detailing Manual [30] was used to assist in connection details.

An ultimate limit state load factor of 1.6 and a service ability limit state load factor of 1.0 (corresponding to the live load factors of SABS 162: 1-1993 The Structural use of Steel Part 1: Limit-States Design [2]) were used in the design of all loading equipment.

Due to the stiffness requirements of the supports and lateral supporting frames unfactored loads were used to create the load and deflection envelopes.

For a summary of the capacity of the MTA refer to Appendix D.

C.1. Load Application with the MTA

C.1.1. Vertical Loads

A vertical load can be applied to the test specimen by using one or more of the following loading bridges:

a. The Gravity Load Simulator

b. 600 kN Hydraulic Actuator Bridge (600 kN Maximum static load)

c. 62.5 kN Hydraulic Actuator Bridge (62.5 kN Maximum static load)

C.1.1.1. The Gravity Load Simulator:

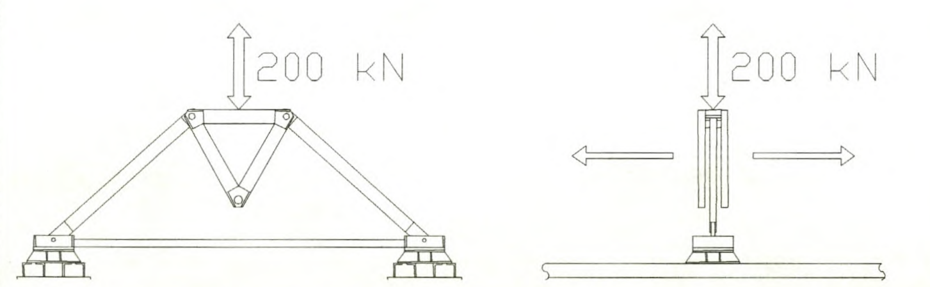


Figure C. 1 Applying a Vertical Load along the Tracks using the Gravity Load Simulator.

For loading refer to Figure C. 1.

The Gravity Load Simulators were designed and build under the supervision of Prof. P. E. Dunaiski (1986).

C.1.1.2. <u>600 kN Hydraulic Actuator Bridge:</u>

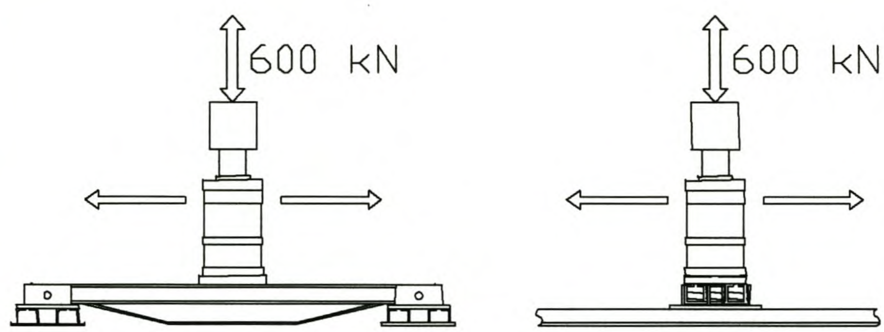


Figure C. 2 Applying a vertical load along and across the Tracks using the 600 kN Actuator Load Bridge.

Load Factor = 1.6 (Live Load)

For loading and load envelopes refer to Figure C. 2, Figure C. 3 and Figure C. 4.

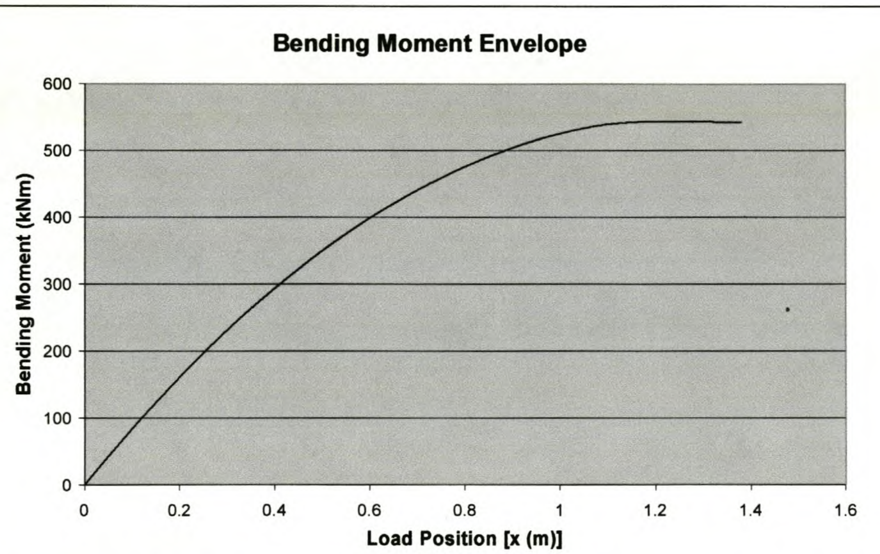


Figure C. 3 Bending Moment Envelope for 600 kN Hydraulic Actuator Bridge

C.1.1.2. 600 kN Hydraulic Actuator Bridge:

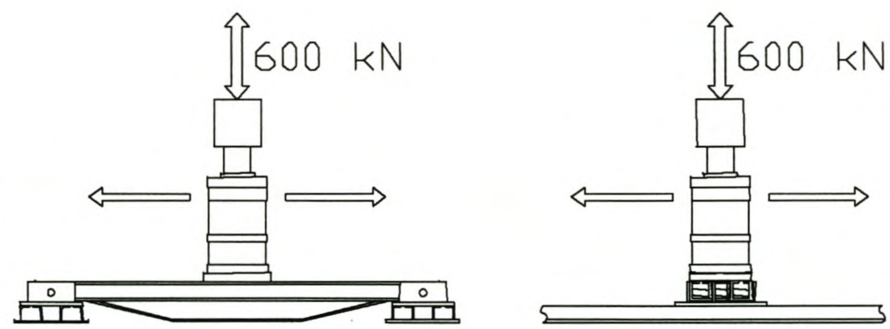


Figure C. 2 Applying a vertical load along and across the Tracks using the 600 kN Actuator Load Bridge.

Load Factor = 1.6 (Live Load)

For loading and load envelopes refer to Figure C. 2, Figure C. 3 and Figure C. 4.

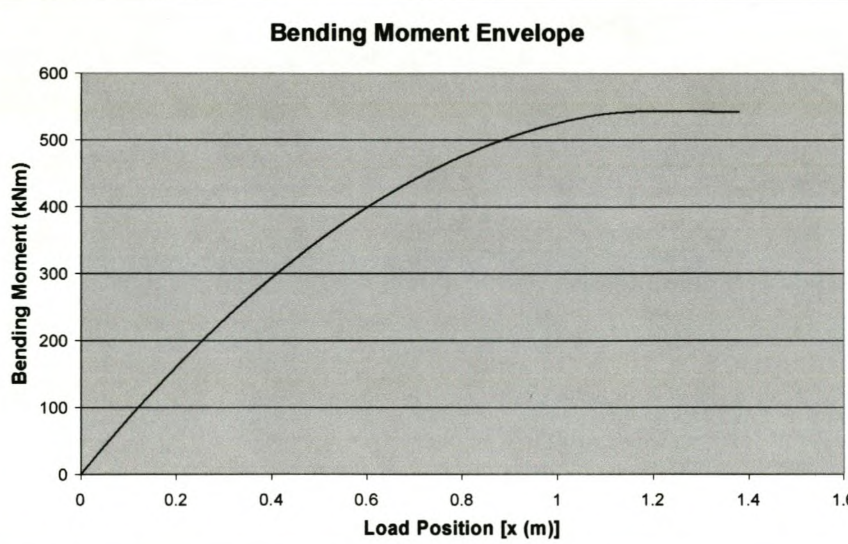


Figure C. 3 Bending Moment Envelope for 600 kN Hydraulic Actuator Bridge

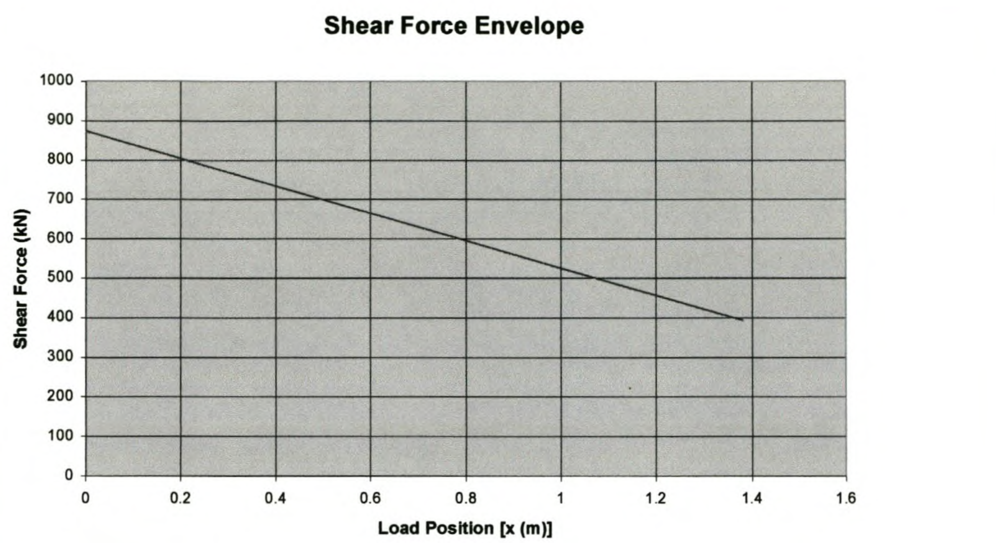


Figure C. 4 Shear Force Envelope for 600kN Hydraulic Actuator Bridge

C.1.1.3. <u>62.5 kN Hydraulic Actuator Bridge:</u>

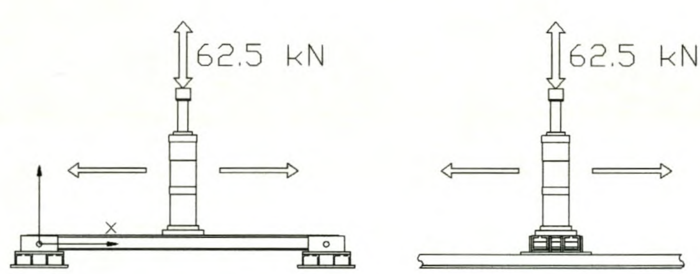


Figure C. 5 Applying a vertical load along and across the Tracks using the 62.5 kN Actuator Load Bridge.

Load Factor = 1.6 (Live Load)

For loading and load envelopes refer to Figure C. 5, Figure C. 6 and Figure C. 7.

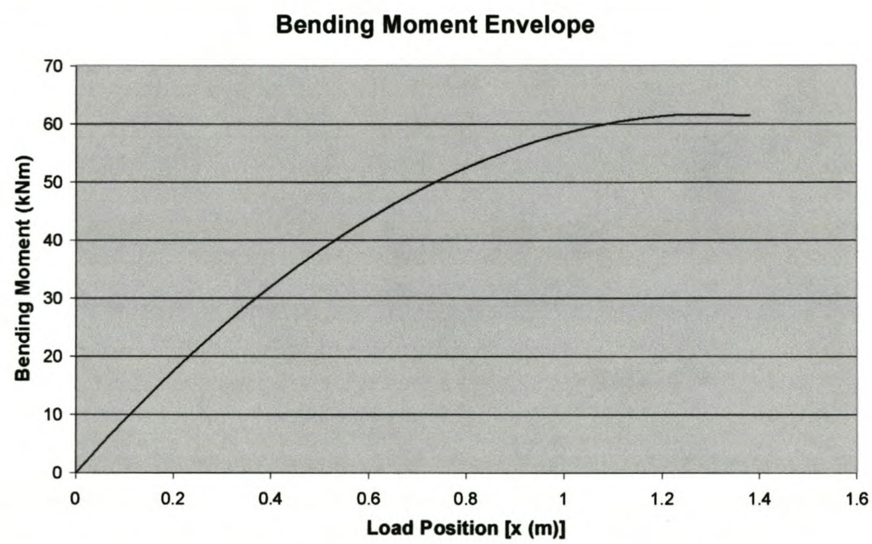


Figure C. 6 Bending Moment Envelope for 600 kN Hydraulic Actuator Bridge

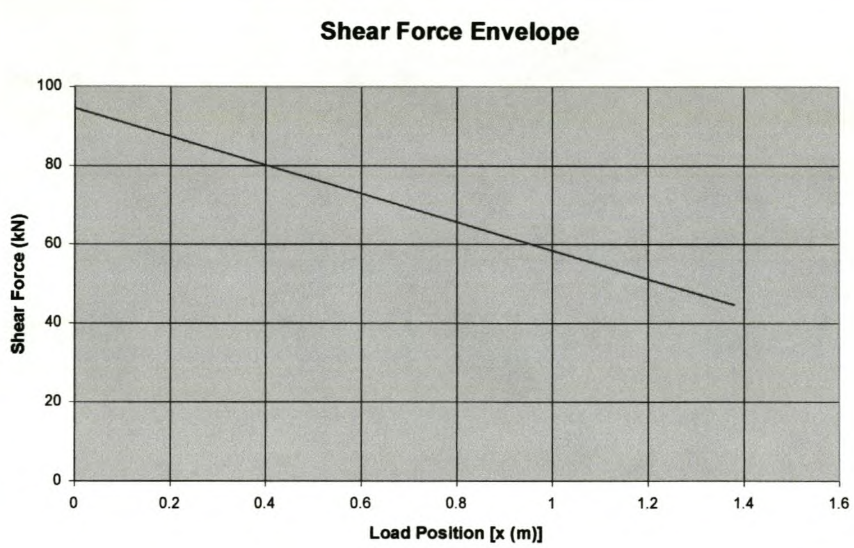


Figure C. 7 Shear Force Envelope for 62.5 kN Hydraulic Actuator Bridge

C.2. Design of the MTA

C.2.1.	Design: Tracks
	The tracks are used for guiding and fixing the loading bridges, supports and lateral supports to the test floor.
C.2.1.1. See Section C.1 and Figure C. 8	Loading: Note: The reactions at the fixing points should not exceed 400 kN vertical and 200 kN horizontal as this will exceed the capacity of the test floor. Two extreme load cases: • Load case 1 Total vertical Load = 684 kN (upwards) • Load case 2 Total vertical Load = 684 kN (downwards)

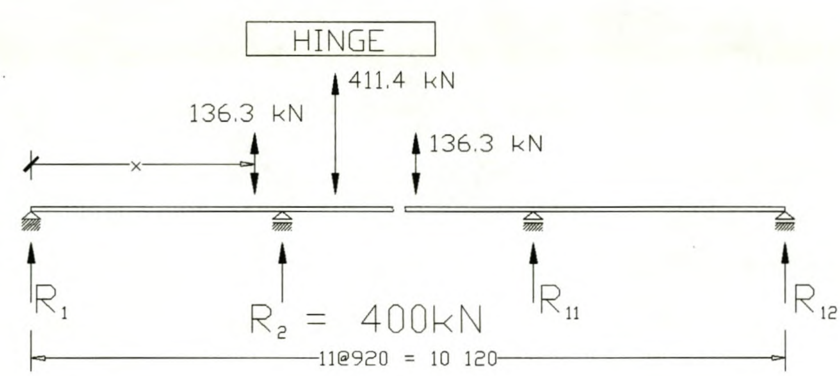


Figure C. 8 Loading on Track: Vertical Loading moving along track

$V_u = 341.9$ kN	$M_u = 77.3$ kNm

C.2.1.2. Properties

Geometry:

11 span simply supported beam, L = 920 mm

Refer to drawings 01-3D-01, 01-01/1 and 01-01/2 for more detail on the tracks.

The cross section is shown in Figure C. 9.

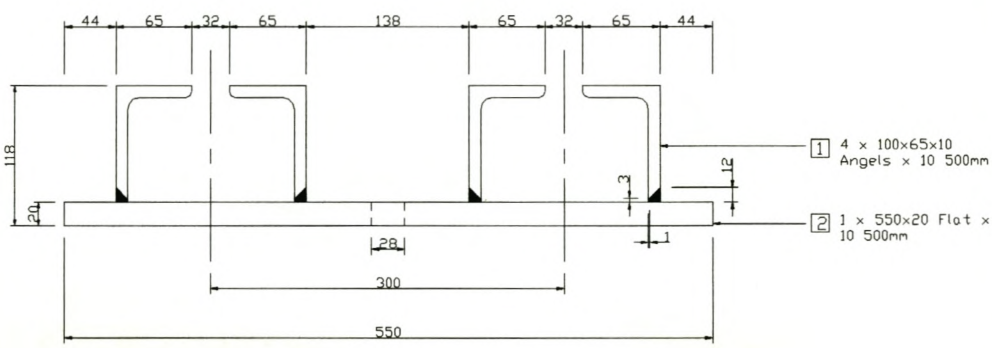


Figure C. 9 Cross section through Track

Section properties for build up section:

$A = 17\ 240\ mm^2$

$y = 38.7$ mm

$I = 31.6 \times 10^6\ mm^4$

	Profile class:			
		b1/t		
SABS 162-1 Table 1	Legs of angles supported at one end:	65/10 = 6.5	$b1/t < 200/\sqrt{f_y} = 11.5$ Class 3	
	Web	(98-10)/10 = 8.8	$b1/t < 1100/\sqrt{f_y} = 63.5$ Class 1	
	Section class: 3			Class 3
C.2.1.3.	**Tracks**			
SABS 162-1 §13.4.	1. Shear: $V_r = \phi A_v F_{vu}$ $= 0.9 \times (4x10x93) \times 0.66 \times 300$ $= 662.4$ kN			
	$V_r > V_u = 341.9$ kN			Vr= 662.4 kN
SABS 162-1 §13.5.	2. Bending: $M_r = \phi Z_e f_y$ $= 0.9x31.6x10^6/(118-38.7) \times 300$ $= 101.3$ kNm			
	$M_r > M_u = 77.3$ kNm			Mr= 101 kNm

SABS 162-1 §15.9.

3. Web yield and crippling:

Bearing length: N = 100 mm

a. Interior loads:

1. $B_r = 1.10\phi t_w(N + 5k)f_y$
   $= 1.10x0.9x10x(100 + 5x10)x300$
   $= 445.5$ kN /web
2. $B_r = 300\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$
   $= 300x0.9x10^2\{1+3(100/98)(10/10)^{1.5}\}\sqrt{(300x10/10)}$
   $= 1899.2$ kN /web

b. End Reactions:

1. $B_r = 1.10\phi t_w(N + 2.5k)f_y$
   $= 1.10x0.9x10x(100 + 2.5 \times 10) \times 300$
   $= 371.3$ kN /web
2. $B_r = 150\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$
   $= 150x0.9x10^2\{1+3(100/98)(10/10)^{1.5}\}\sqrt{(300x10/10)}$
   $= 949.6$ kN /web

C.2.1.3

Base Plate:

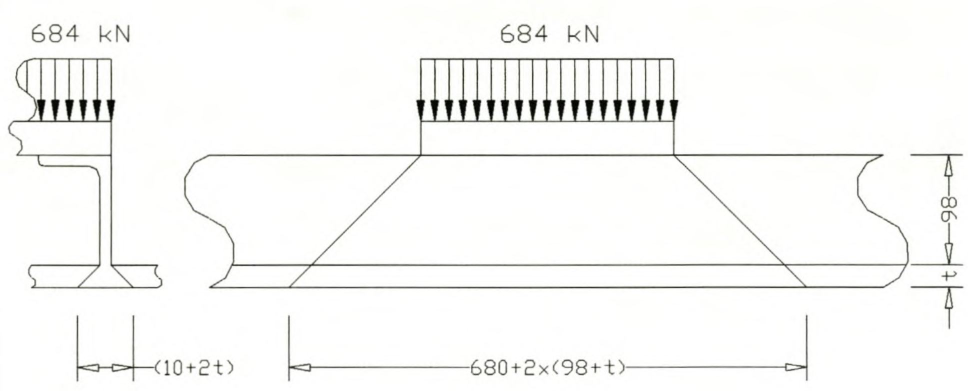
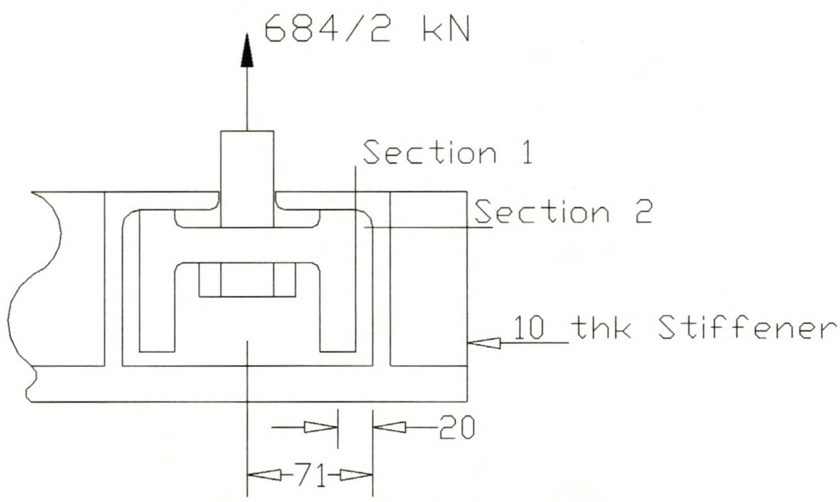


Figure C. 10 Base plate design of track.

	Refer to Figure C. 10.	
SAISC Structural Steelwork Connections, (12.1)	**1. Reinforced Concrete Floor Slab:** $B_r = 0.4f_{cu}$ $= 0.4x20$ $= 8$ MPa Area $= 4x(10+2t)x(680+2x(98+t))$ $= 4x(10+2x20)x(680+2x(98+20))$ $= 183.2x10^3$ mm^2 $\sigma_b = F/A$ $= 684x10^3/183.2x10^3$ $= 3.7$ MPa $\sigma_b < B_r = 8$ MPa	
SAISC Structural Steelwork Connections, (12.2)	**2. Base Plate Thickness:** Minimum base thickness with a = 44 mm: $t_p = \sqrt{(3\sigma_b a^2/0.9f_y)}$ $= \sqrt{(3x3.7x44^2/0.9x300)}$ $= 8.9$ mm $t = 20$ mm $> t_p = 8.9$ mm	

C.2.1.4.	**Bending of Angles:** Refer to Figure C. 11 for position of bending sections.	
	 	
	Figure C. 11 Bending of Angle Legs	
	M_{u1} = 684x10^3/4x10 = 1.71 kNm M_{u2} = 684x10^3/4x25 = 4.28 kNm	
SABS 162-1 §13.5.	Bending Resistance at section 1: M_{r1} = $\phi z_e f_y$ = 0.9x10^2/6x680x300 = 3.06 kNm $M_{r1} > M_{u1}$ = 1.71 kNm	

Bending Resistance at section 2:

With web stiffeners: 10 thk / 460mm spacing

Properties at section 2:

A	= 8180 mm^2	$\bar{y}$	= 7.9 mm
I	= 775.312x10^3 mm^4	z_e	= 16.820x10^3 mm^3

SABS 162-1 §13.5.

M_{r2} $= \phi z_e f_y$

$= 0.9 \times 16.82 \times 10^3 \times (680+50) \times 300$

$= 4.54$ kNm

$M_{r2} > M_{u2} = 4.28$ kNm

C.2.1.5. Welding of Angles, Web Stiffeners & Base Plate:

Weld to SASCH Table 6.16: Single bevel Manual groove weld:

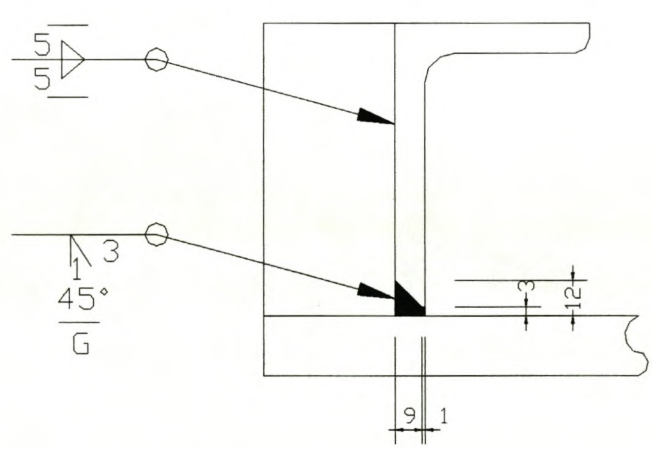


Figure C. 12 Welding detail of web and base plate

Welding detail is shown in Figure C. 12.

Use E70XX electrodes

	1. Angles:	
SABS162-1: Table 3	**Axial Loading:** a) $T_r = C_r = \phi_w A_w f_{uw}$ $= 0.67x10x480$ $= 3.22$ kN/mm b) $T_r = C_r = \phi A_w f_y$ $= 0.9x10x300$ $= 2.7$ kN/mm	
SABS162-1: Table 3	**Shear:** a) $V_r = 0.67\phi_w A_w f_{uw}$ $= 0.67x0.67x10x10500x480$ $= 22\ 624.6$ kN b) $V_r = 0.67\phi A_w f_y$ $= 0.67x0.9x10x10500x300$ $= 18\ 994.5$ kN $V_r > V_u = 200$ kN	
	2. Web Stiffeners:	
SABS162-1:1 Table 3	**Shear:** a) $V_r = 0.67\phi_w A_w f_{uw}$ $= 0.67x0.67x5x2x(44+98)x480$ $= 681.6$ kN b) $V_r = 0.67\phi A_w f_y$ $= 0.67x0.9x10x(44+98)x300$ $= 462.0$ kN	

C.2.1.6. **Torsion capacity of Tracks**

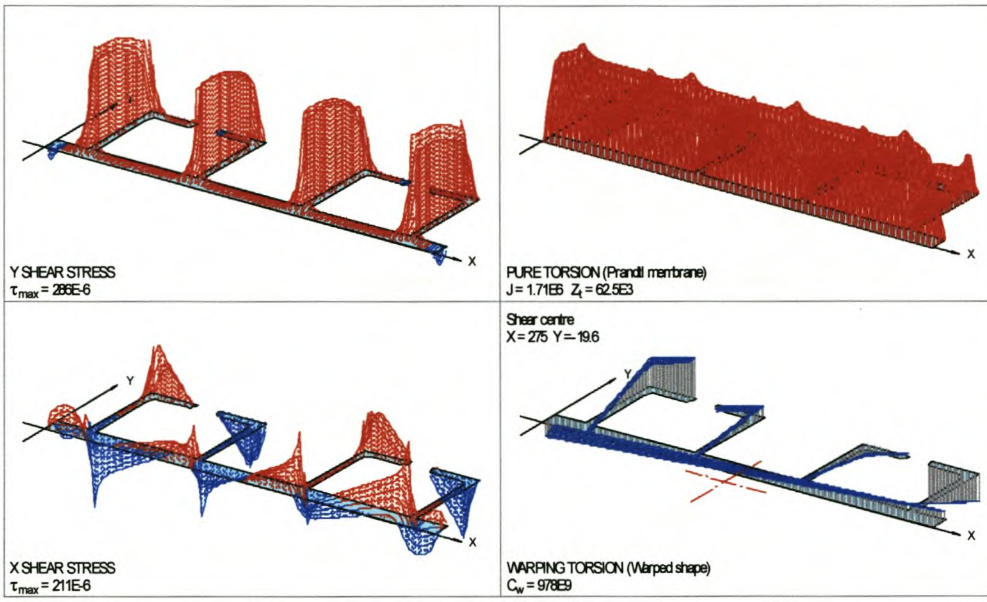


Figure C. 13 Torsional Properties of a Track

The torsional properties of the tracks are calculated using Prokon Software and is indicated in Figure C. 13.

$T_{max} = \sigma Z_t$, with σ = 195 MPa

T_{max} = 195x62.5x10^3

= 12.18 kNm

T_{max} = 12.18 kNm

C.2.1.7. **Holding Down Bolts:**

Use 26E DYWIDAG bars:

DYWIDAG Single Thread Bar Tendons: Technical data

$T_r = \phi \beta_s A_z$

= 0.9x460

= 414 kN

$T_r > T_u = 400$ kN

T_r = 412 kN

C.2.2.	<u>Design: Load Bridges</u> The loading bridges are used to apply a vertical load between the tracks. Three loading bridges are designed for use: a. The Gravity Load Simulator b. 600 kN Hydraulic Actuator Bridge c. 62.5 kN Hydraulic Actuator Bridge	
C.2.2.1.	<u>The Gravity Load Simulator</u> <u>Loading</u>	
See Section C.1. and Drawings: SR/01 – SR/27	• Capacity of Gravity Load Simulator: Vertical Load (upwards) = 200 kN Vertical Load (downwards) = 150 kN • Load transfer to Track Connector: Vertical Load = 1.6x132 = 211.2 kN (Not Critical) <u>Properties</u> Geometry: Mechanism, L = 2760 mm, h = 927.415 mm. Refer to drawings 03-3D-03, 03-03/1 and SR/01 to SR/27. The Gravity Load Simulator is shown in Figure C. 14.	

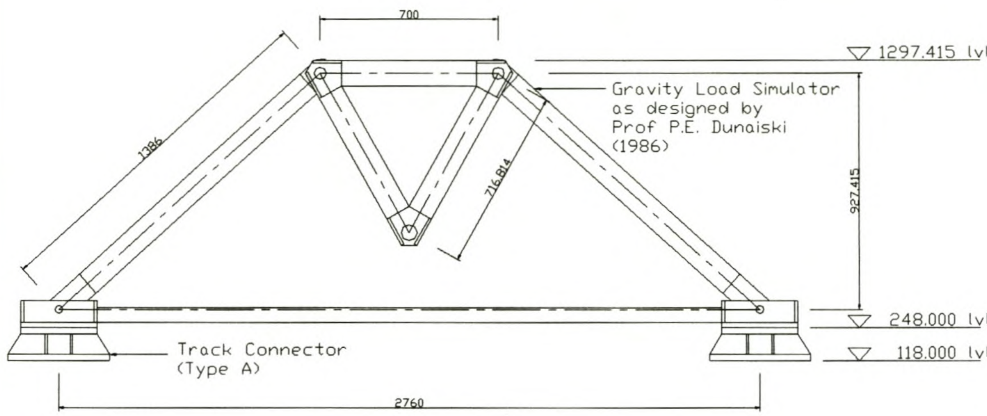


Figure C. 14 The Gravity Load Simulator

Gravity Load Simulator Design:

The Gravity Load Simulators were designed and build under the supervision of Prof. P. E. Dunaiski (1986).

Track Connector (Type A) Design:

Refer to drawings 03-3D-04 and 03-03/2.

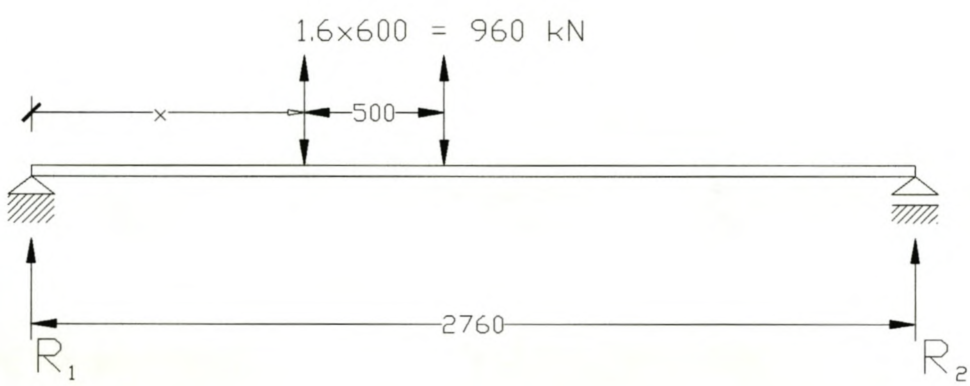
Minimum Axial Properties of Column:

$A = 6400\ mm^2$ $r = 44.51\ mm$

$I = 12.68x10^3\ mm^4$

SABS 162-1: §13.3	**1. Axial Load:** $\lambda = kL/r\sqrt{(f_y/\pi^2E)} = 0.022$ $C_r = \phi A f_y(1+\lambda^{2n})^{-1/n}$ $= 0.9x6400x300(1+0.022^{2x1.34})^{-1/1.34}$ $= 1\ 727.9$ kN $C_r > C_u = 211.2$ kN **2. Top Base Plate:** $\sigma_b = F/A$ $= 211.2x10^6/(200x200)$ $= 5.3$ MPa Minimum base thickness with a = 100 mm	
SAISC Structural Steelwork Connections, (12.1)	$t_p = \sqrt{3\sigma_b a^2/\phi f_y}$ $t_p = \sqrt{3x5.3x100^2/0.9/300}$ $= 24.2$ mm $t = 25 \text{ mm} > t_p$ **3. Bottom Base Plate:** $\sigma_b = F/A$ $= 132x10^6/(300x300)$ $= 2.3$ MPa	

SAISC Structural Steelwork Connections, (12.2)	Minimum base thickness with a = 100 mm $t_p = \sqrt{3\sigma_b a^2/\phi f_y}$ $t_p = \sqrt{3x2.3x150^2/0.9/300}$ $= 24.2$ mm $t = 25\text{ mm} > t_p$	
	Welding Column Plates & Base Plates: Welding fillet 5 thick all round. (Use E70XX electrodes)	
SABS 162-1: Table 3	<u>4. Shear:</u> a) $V_r = 0.67\phi_w A_w f_{uw}$ $= 0.67x0.67x(5/\sqrt{2})x8x200x480$ $= 1218$ kN b) $V_r = 0.67\phi A_m f_y$ $= 0.67x0.9x(5/\sqrt{2})x8x200x300$ $= 1023$ kN $V_r > V_u = 211.2$ kN	

C.2.2.2.	<u>600 kN Servo Hydraulic Actuator Bridge</u>	
See Section C.1.	<u>Loading</u> • Most severe Loading on bridge: Total vertical Load = 1.6x600= 960 kN (up or downwards). Note: The end reactions should not exceed 684 kN, as this will cause the capacity of the test floor to be exceeded (See Figure C. 15).	
		
	Figure C. 15 Loading on Bridge: Vertical Load moving across bridge.	
	<u>Properties</u> Geometry: Simply supported beam, L = 2760 mm Refer to drawings 03-3D-01, 03-01/1, 03-01/2 and 03-01/3. Also refer to Figure C. 16 and Figure C. 17 for extracts of drawings 03-01/1 and 03-01/2.	

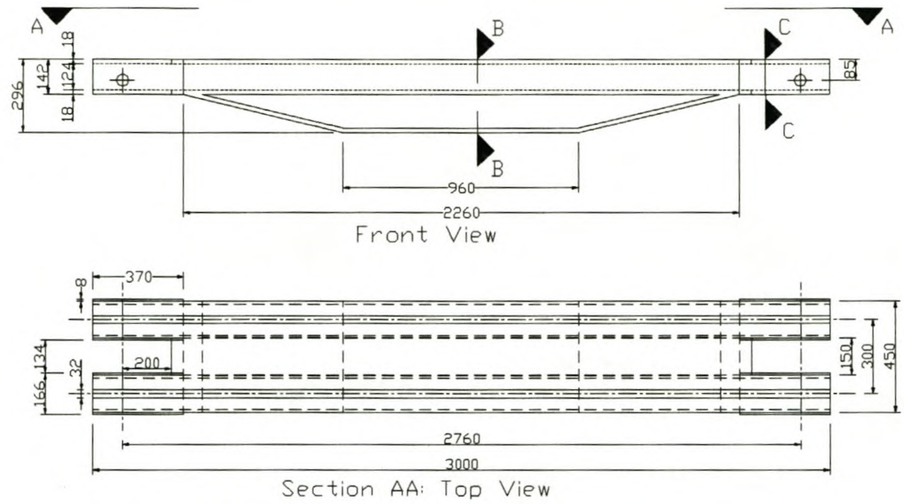


Figure C. 16. Detail of 600 kN Servo Hydraulic Actuator Bridge.

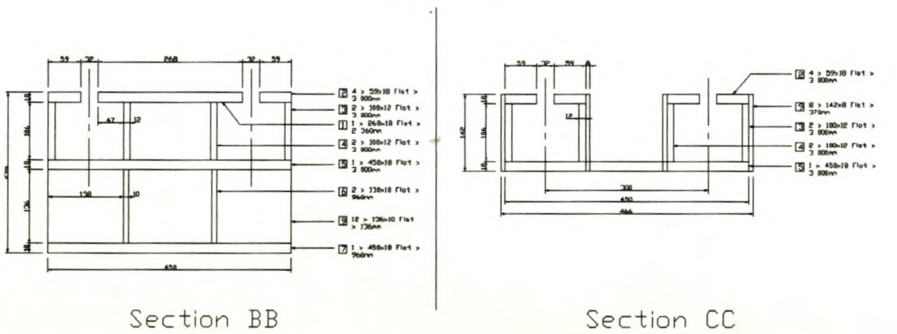


Figure C. 17. 600 kN Servo Hydraulic Actuator Bridge: Section BB and CC

Section properties for built up sections:

Section BB

$\bar{y}$ = 154.0 mm

A = 30 956 mm^2

I = 341.67 x 10^6 mm^4

Section CC

$\bar{y}$ = 67.5 mm

A = 20 134 mm^2

I = 62.8 x 10^6 mm^4

Profile class:

Reference		$b1/t$		
SABS 162-1 Table 1	Section BB: Bottom Flanges	$138/18 = 7.67$	$b_1/t < 145/\sqrt{f_y} = 8.37$ Class 1	
	Section BB: Top Web	$106/10 = 10.6$	$b_1/t < 1100/\sqrt{f_y} = 63.5$ Class 1	
	Section BB: Bottom Web	$136/10 = 13.6$	$b_1/t < 1100/\sqrt{f_y} = 63.5$ Class 1	

Section class: 1

Class 1

<u>Section Design:</u>

SABS 162-1 §13.4.

<u>1. Shear:</u>

$V_r = \phi A_v f_{vu}$

$V_r > V_u$ (refer to Figure C. 18)

Figure C. 18. 600kN Bridge: Shear Design.

SABS 162-1 §13.5.

2. Bending:

$M_r = \phi Z_e f_y$

$$M_r > M_u \text{ (refer to Figure C. 19)}$$

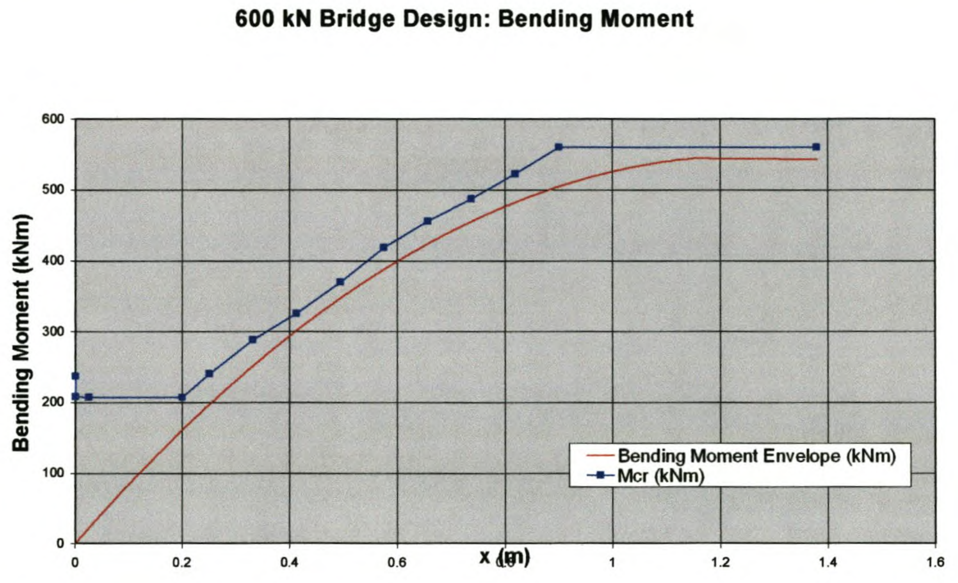


Figure C. 19. 600kN Bridge Design: Bending Moment

SABS 162-1 §15.9.

3. Web yield and crippling:

Bearing length: N = 100 mm

For Section BB & CC (12 thick flanges)

a. Interior loads:

1. $B_r = 1.10\phi t_w(N + 5k)f_y$

   $= 1.10 \text{x} 0.9 \text{x} 12 \text{x} (100 + 5 \text{x} 18) \text{x} 300$

   $= 677.2$ kN /web

2. $B_r = 300\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$

   $= 300 \text{x} 0.9 \text{x} 12^2\{1+3(100/106)(12/18)^{1.5}\}\sqrt{(300 \text{x} 12/18)}$

   $= 1396.9$ kN /web

b. End Reactions:

1. $B_r = 1.10\phi t_w(N + 2.5k)f_y$

$= 1.10x0.9x12x(100 + 2.5x20)x300$

$= 534.6$ kN /web

2. $B_r = 150\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$

$= 150x0.9x12^2\{1+3(100/106)(12/20)^{1.5}\}\sqrt{(300x12/20)}$

$= 603.8$ kN /web

$B_r > B_u$

For Section BB (10 thick flanges)

a. Interior loads:

1. $B_r = 1.10\phi t_w(N + 5k)f_y$

$= 1.10x0.9x12x(100 + 5 \times 18) \times 300$

$= 677.2$ kN /web

2. $B_r = 300\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$

$= 300x0.9x12^2\{1+3(100/106)(12/18)^{1.5}\}\sqrt{(300x12/18)}$

$= 1396.9$ kN /web

b. End Reactions:

1. $B_r = 1.10\phi t_w(N + 2.5k)f_y$

$= 1.10x0.9x12x(100 + 2.5x20)x300$

$= 534.6$ kN /web

2. $B_r = 150\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$

$= 150x0.9x12^2\{1+3(100/106)(12/20)^{1.5}\}\sqrt{(300x12/20)}$

$= 603.8$ kN /web

$B_r > B_u$

4. Bending of Flanges:

Refer to Figure C. 20 for position of bending sections.

$M_{u1} = 960x10^3/8x(3+5)$

$= 0.96$ kNm

$M_{u2} = 960x10^3/8x(3+5+6)x(101/124)$

$= 1.37$ kNm

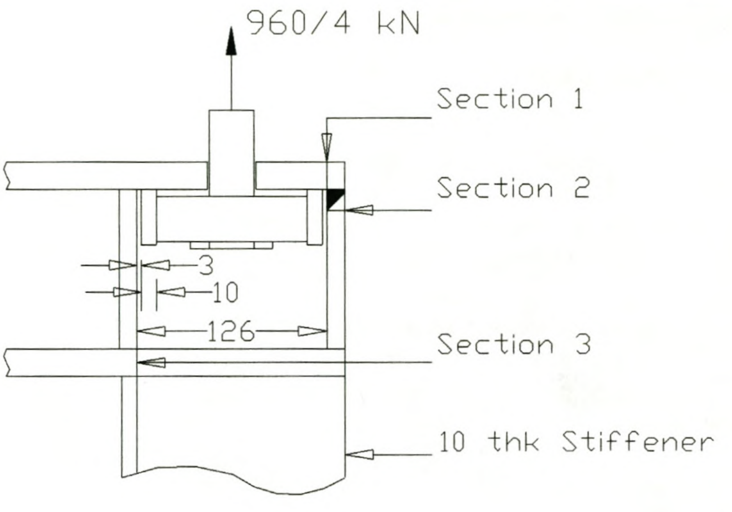


Figure C. 20. Bending of Angle Legs

M_{u3} $= 960x10^3/8x(138\text{-}12\text{-}3\text{-}5)$

$= 14.16$ kNm

SABS 162-1 §13.5.

Bending Resistance at Section 1:

$M_{r1} = \phi z_e f_y$

$= 0.9x18^2/6x180x300$

$= 2.62$ kNm

$M_{r1} > M_{u1} = 0.96$ kNm

Bending Resistance at Section 2:

$M_{r2} = \phi z_e f_y$

$= 0.9x12^2/6x(180+2x(3+6+9+14))x300$

$= 1.58$ kNm

$M_{r2} > M_{u2} = 1.37$ kNm

Bending Resistance at Section 3:

(without any stiffeners)

$M_{r3} = \phi z_e f_y$

$= 0.9x18^2/6x(180+2x(124+118))x300$

$= 9.68$ kNm

$M_{r3} < M_{u3} = 14.16$ kNm

Add Stiffeners: 10 thick with 320 mm spacing

Bending between stiffeners:

$M_r = 60x10^3x320/2-60x10^3x90/2$

$= 6.9$ kNm

Property of Section between Stiffeners:

A	= 4818 mm^2	$\bar{y}$	= 52.7 mm
I	= 13304.3x10^3 mm^4	Z_e	= 149.0x10^3 mm^3

SABS 162-1 §13.5.

$M_r = \phi z_e f_y$

$= 0.9x149.0x10^3x300$

$= 40.23$ kNm

$M_r > M_u = 6.9$ kNm

5. Stiffeners Design:

Axial Properties of Stiffener:

A = 1380 mm^2 r = 2.886 mm

I = 11500 mm^4

SABS162-1: §13.3

Axial Loading:

$\lambda = kL/r \sqrt{(f_y/\pi^2 E)} = 0.581$

$C_r = \phi A f_y (1+\lambda^{2n})^{-1/n}$

$= 0.9x1380x300(1+0.581^{2x1.34})^{-1/1.34}$

$= 318.6$ kN

$C_r > C_u = 60$ kN

6. Welding of Flanges, Webs & Web Stiffeners:

Weld to SASCH Table 6.16: Single Bevel Manual groove weld:

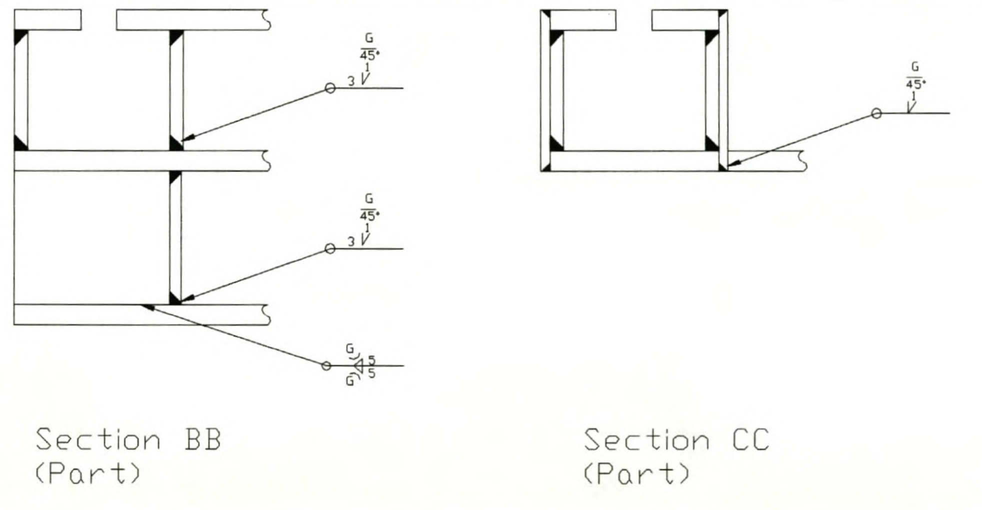


Figure C. 21. Welding detail of web and base plate

Welding detail is shown in Figure C. 21.

(Use E70XX electrodes)

12 Thick Webs:

SABS162-1: Table 3

Axial Loading:

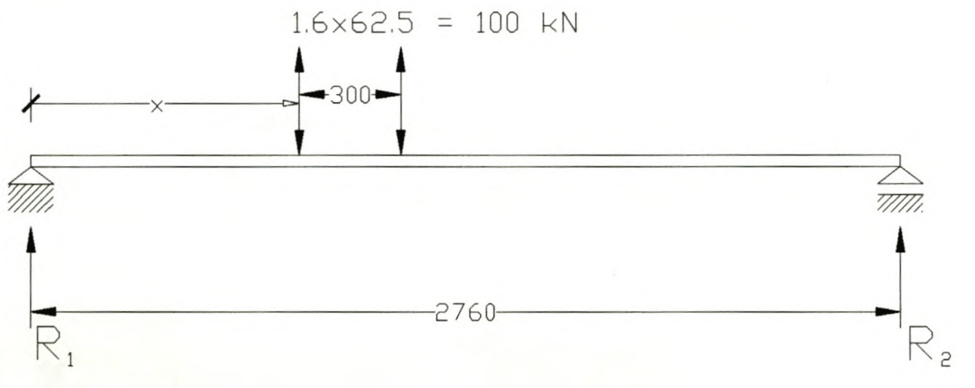
a) $T_r = C_r = \phi_w A_w f_{uw}$

$= 0.67x12x480$

$= 3.86$ kN/mm

	b) $T_r = C_r = \phi A_w f_y$ $= 0.9x12x300$ $= 3.24$ kN/mm	
SABS162-1: Table 3	**Shear:** a) $V_r = 0.67\phi_w A_w f_{uw}$ $= 0.67x0.67x12x480$ $= 2.59$ kN/mm b) $V_r = 0.67\phi A_w f_y$ $= 0.67x0.9x12x300$ $= 2.17$ kN/mm	
	<u>10 Thick Webs:</u>	
SABS162-1: Table 3	**Axial Loading:** a) $T_r = C_r = \phi_w A_w f_{uw}$ $= 0.67x10x480$ $= 3.22$ kN/mm b) $T_r = C_r = \phi A_w f_y$ $= 0.9x10x300$ $= 2.70$ kN/mm	
SABS162-1: Table 3	**Shear:** a) $V_r = 0.67\phi_w A_w f_{uw}$ $= 0.67x0.67x10x480$ $= 2.15$ kN/mm b) $V_r = 0.67\phi A_w f_y$ $= 0.67x0.9x10x300$ $= 1.81$ kN/mm	

SABS162-1: Table 3	<u>Web Stiffeners</u>: Shear: a) $V_r = 0.67\phi_w A_w f_{uw}$ $= 0.67 x 0.67 x 5 x 2 x (136) \times 480$ $= 293.0$ kN b) $V_r = 0.67\phi A_w f_y$ $= 0.67 x 0.9 x 10 x (136) \times 300$ $= 249.6$ kN Welding as shown in Figure C. 21 is sufficient.	

C.2.2.3.	<u>62.5kN Servo Hydraulic Actuator Bridge:</u>	
See Section C.1.	<u>Loading</u>: • Most severe Loading on bridge: Total vertical Load = 1.6x62.5= 100 kN (up or downwards). (See Figure C. 22).	
		
	Figure C. 22. Loading on Bridge: Vertical Loading moving across bridge.	
	<u>Properties</u> Geometry: Simply supported beam, L = 2760 mm Refer to drawings 03-3D-02, 03-02/1, 03-02/2 and 03-02/3. Also refer to Figure C. 23 and Figure C. 24 for extracts of drawings 03-02/1 and 03-02/2.	

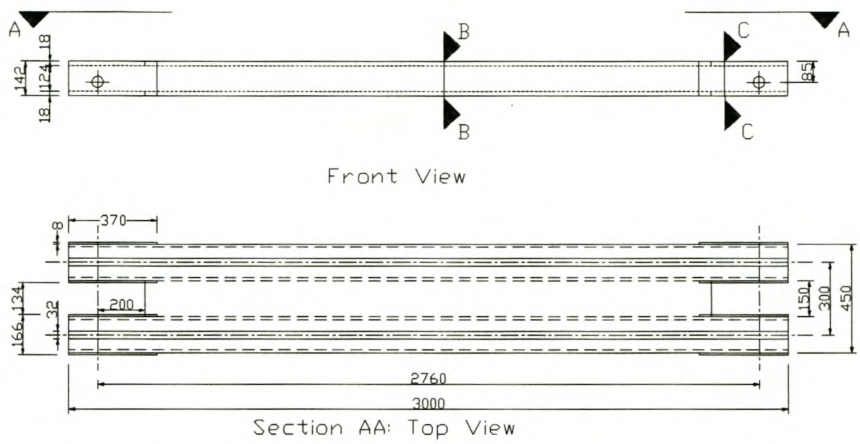


Figure C. 23. Detail of 62.5 kN Servo Hydraulic Actuator Bridge.

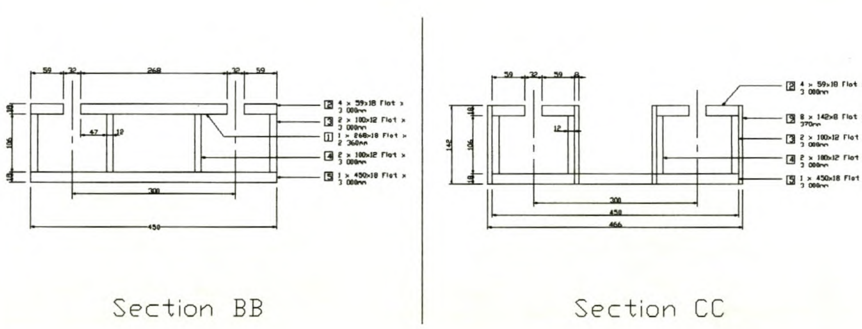


Figure C. 24. 62.5 kN Servo Hydraulic Actuator Bridge: Section BB and CC

Section properties for built up sections:

Section BB

$\bar{y}$ = 67.5 mm

A = 20 136 mm^2

I = 62.8 x 10^6 mm^4

	Profile class:			
		b1/t		
SABS 162-1 Table 1	Section BB Flanges	59/18 = 3.28	$b_1/t < 145/\sqrt{f_y} = 8.37$ Class 1	
	Section BB Web:	106/10 = 10.6	$b_1/t < 1100/\sqrt{f_y} = 63.5$ Class 1	
	Section class: 1			Class 3
	Section Design:			
SABS 162-1 §13.4.	1. Shear: $V_r = \phi A_v f_{vu}$ $V_r > V_u$ (refer to Figure C. 25)			

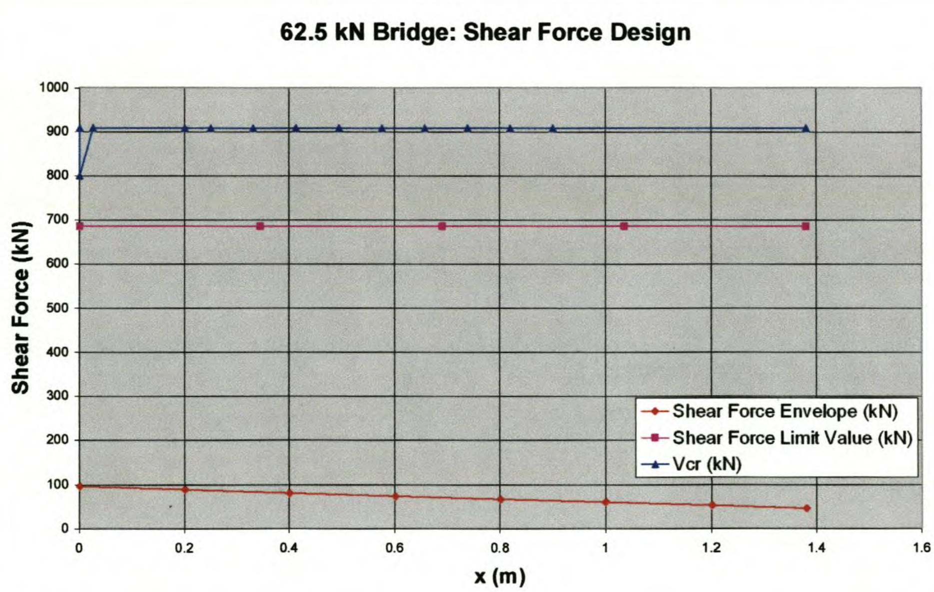


Figure C. 25. 62.5kN Bridge: Shear Design.

SABS 162-1 §13.5.

2. Bending:

$M_r = \phi Z_e f_y$

$M_r > M_u$ (refer to Figure C. 26)

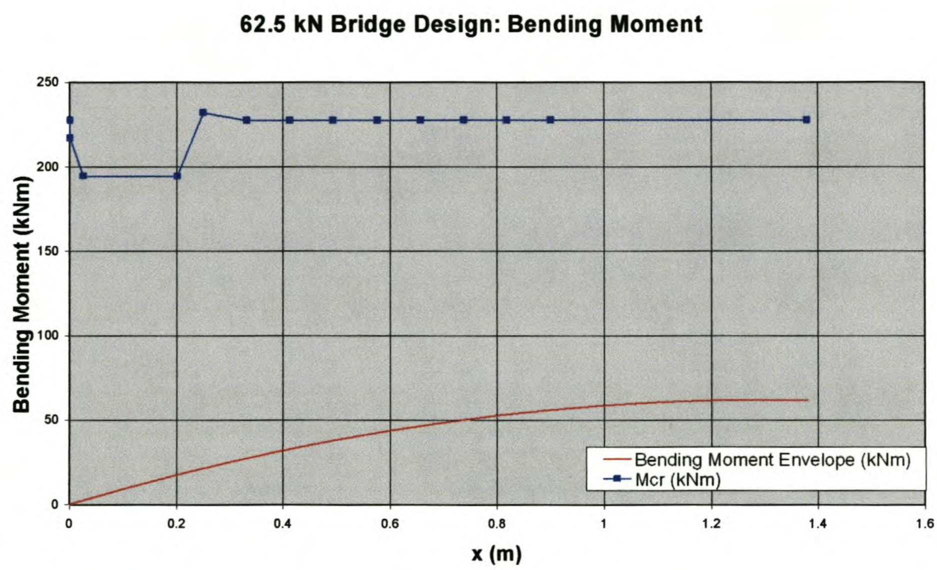


Figure C. 26. 62.5 kN Bridge Design: Bending Moment

SABS 162-1 §15.9.

3. Web yield and crippling:

Bearing length: N = 100 mm

For Section CC

a. Interior loads:

1. $B_r = 1.10\phi t_w(N + 5k)f_y$

$= 1.10\text{x}0.9\text{x}12\text{x}(100 + 5\text{x}18)\text{x}300$

$= 677.2$ kN /web

2. $B_r = 300\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$

$= 300\text{x}0.9\text{x}12^2\{1+3(100/106)(12/18)^{1.5}\}\sqrt{(300\text{x}12/18)}$

$= 1396.9$ kN /web

b. End Reactions:

1. $B_r = 1.10\phi t_w(N + 2.5k)f_y$

$= 1.10x0.9x12x(100 + 2.5x20)x300$

$= 534.6$ kN /web

2. $B_r = 150\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$

$= 150x0.9x12^2\{1+3(100/106)(12/20)^{1.5}\}\sqrt{(300x12/20)}$

$= 603.8$ kN /web

$B_r > B_u$

4. Bending of Flanges:

Refer to Figure C. 27 for position of bending sections.

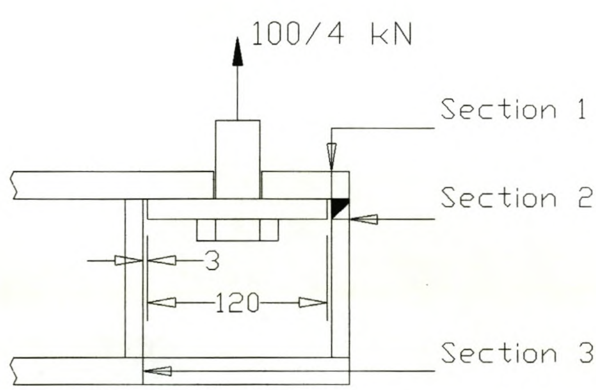


Figure C. 27. Bending of Angle Legs

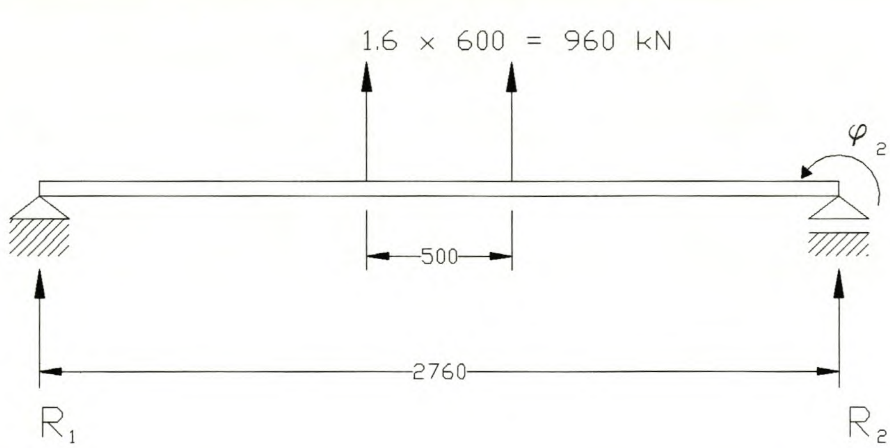
$M_{u1} = 100x10^3/8x(44/2+3)$

$= 0.31$ kNm

$M_{u2} = 100x10^3/8x(44/2+3+6)$

$= 0.39$ kNm

	$M_{u3} = 100x10^3/8x(138-6-3-44/2)$ $= 1.34$ kNm	
SABS 162-1 §13.5.	Bending Resistance at Section 1: $M_{r1} = \phi z_e f_y$ $= 0.9x18^2/6x2x63x300$ $= 1.83$ kNm $M_{r1} > M_{u1} = 0.31$ kNm Bending Resistance at Section 2: $M_{r2} = \phi z_e f_y$ $= 0.9x12^2/6x(2x(69+9+14)x300$ $= 1.19$ kNm $M_{r2} > M_{u2} = 0.39$kNm Bending Resistance at Section 3: $M_{r3} = \phi z_e f_y$ $= 0.9x18^2/6x2x(53+118+132)x300$ $= 8.84$ kNm $M_{r3} > M_{u3} = 1.34$ kNm <u>5. Welding of Flanges, Webs & Web Stiffeners:</u> Welding as for 600 kN Servo Hydraulic Actuator Bridge. Detail as shown in Figure C. 21 Section CC (Part). (Use E70XX electrodes)	

C.2.3.	Design: Hinge The hinge connects the hydraulic actuator bridges to the tracks. The purpose of the hinge is to eliminate torsion on the tracks. Refer to drawings 02-3D-01, 02-3D-02, 02-01/1, 02-03/1 for more detail on the hinge and fixing brackets. The hinge is shown in Figure C. 30.	
C.2.3.1.	Loading:	
See Section C.1., Figure C. 28 and Figure C. 29	• Two extreme loading cases: Load case 1: 600kN hydraulic actuator at centre of loading bridge. Load case 2: 600kN hydraulic actuator at end of loading bridge. Note: The maximum loading on the hinge should not exceed 684 kN, as this will cause the capacity of the test floor to be exceeded (Refer to Figure C. 28 and Figure C. 29).	
		
	Figure C. 28. Load case 1: Vertical load at centre of loading bridge: R_2 = -480 kN, ϕ = -0.0821 radians.	

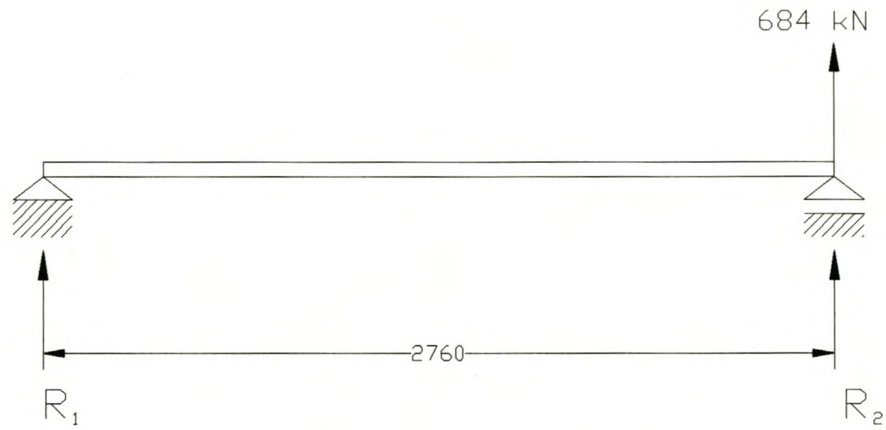


Figure C. 29. Load case 2: Vertical load end of loading bridge:

R_2 = -684 kN, ϕ = 0 radians.

C.2.3.2.	<u>Hinge Design:</u>	
Permaglide Plain Bearings, INA Catalogue 705	For Frictionless rotation use Permaglide® P10 bearings. <u>Technical Data:</u> Inside diameter of bush: $d_1 = 50$ mm. Bearing Load: F = 684 kN (Static Load)	
Catalogue705 Table 1	<u>1. Permissible specific bearing load:</u> Static: $p_{max} = 250\ N/mm^2$ Very low Sliding speeds: $p_{max} = 140\ N/mm^2$ Rotating, oscillating: $p_{max} = 56\ N/mm^2$ Minimum width of Bush: $p = F/d_1.b$ $b_{min} = 684x10^3/250x50$ $= 54.7mm$	

	Use 4 x Webs 20 mm thick with 4 x PAP 5020 P10 Maintenance free INA Bearings 2. Load capacity of bearings:	4 Webs 20 mm thick

Loading Condition	F_{max}
Static: Very low Sliding speeds: Rotating, oscillating:	$F_{max} = p_{max}.d_1.b = 1000$ kN $F_{max} = p_{max}.d_1.b = 560$ kN $F_{max} = p_{max}.d_1.b = 224$ kN

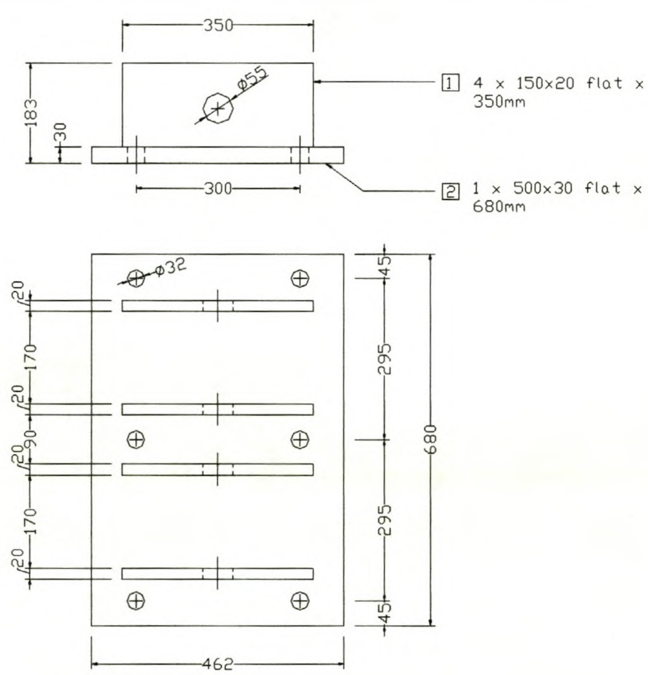
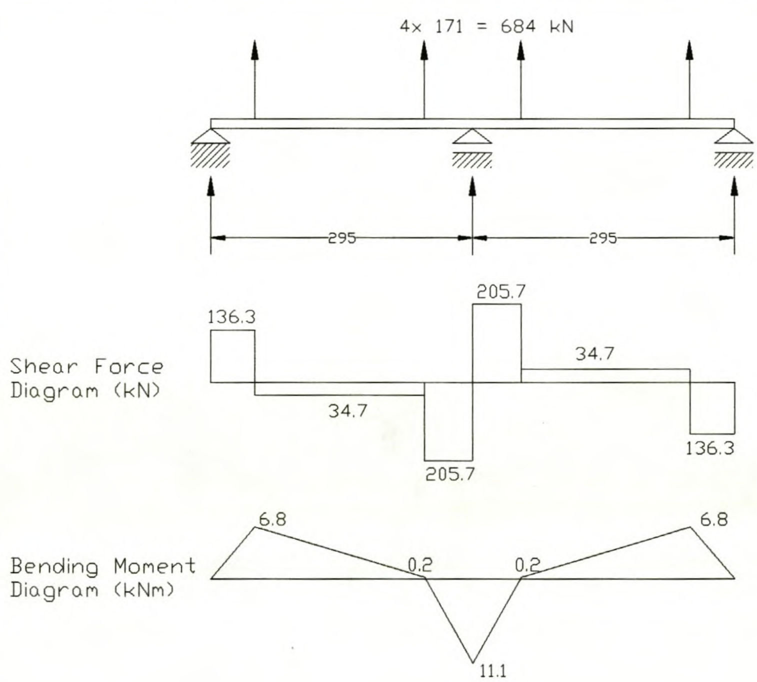


Figure C. 30. Detail of Hinge

C.2.3.2.	<u>Base Plate Design</u>: For Member forces refer to Figure C. 31.	
SABS 0162-1: §13.4.2	<u>1. Shear:</u> $V_r = 0.66\phi Afy$ $= 0.66x0.9x30x462x300$ $= 2470$ kN $V_r > V_u = 205.7$ kN	
		
	Figure C. 31. Base plate design: Shear Force and Bending Moment Diagrams	
SABS 0162-1: §13.5 (a)	<u>2. Bending:</u> $M_r = \phi z_e f_y$ $= 0.9x1/6x30^2x462x300$ $= 18.7$ kN $M_r > M_u = 11.1$ kN	

C.2.3.3. **Hinge Web Plate Design:**

1. Bearing: Pin and Web Interaction:

SABS 0162-1: §13.10 (1)

$B_r = \phi t a f_u$
$= 0.67x20x83x450$
$= 500.5$ kN

SABS 0162-1: §13.10 (2)

$B_r = 3\phi t d f_u$
$= 3x0.67x20x55x450$
$= 995.0$ kN

$B_r = 500.5$ kN $> 684/4 = 171$ kN

2. Axial Tension:

SABS162-1: §13.2 (a)

a) $T_r = \phi A_g f_y$
$= 0.9x20x350x300$
$= 1\ 880$ kN

SABS162-1: §13.2 (b)

b) $T_r = 0.85\phi A_{ne} f_u$
$= 0.85x0.9x20x(350\text{-}55)x450$
$= 2\ 031$ kN

$T_r > T_u = 205.7$ kN

3. Bending & Compression:

For Member forces refer to Figure C. 32.

$M_r = \phi z_e f_y$
$= 0.9x1/6x20^2x350x300$
$= 6.3$ kN

$r = \sqrt{233.3x10^3/700} = 5.77$

$\lambda = kL/r\sqrt{(f_y/\pi^2 E)} = 2.0x70.0/5.77x\sqrt{(300/3.14^2x200x10^3)} = 0.299$

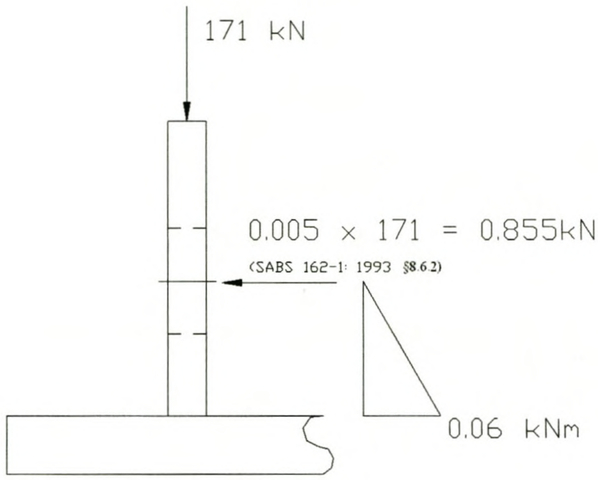


Figure C. 32. Web Plate in Compression and Bending

SABS162-1: §13.3

$C_r = \phi A f_y (1+\lambda^{2n})^{-1/n}$

$= 0.9\text{x}20\text{x}350\text{x}300(1+0.299^{2\text{x}1.34})^{-1/1.34}$

$= 1836.4$ kN

Sufficient capacity for Bending & Axial Compression

4. Welding of Web & Base Plates:

Weld to SASCH Table 6.16: Double Bevel Manual groove weld:

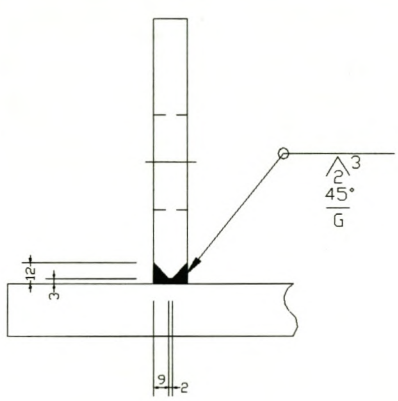


Figure C. 33. Welding detail of web and base plate

	Refer to Figure C. 34.	
SABS162-1: Table 3	**Axial Loading:**	
	a) $T_r = C_r = \phi_w A_w f_{uw}$	
	$= 0.67 x 20 x 350 x 480$	
	$= 2251.2$ kN	
	b) $T_r = C_r = \phi A_w f_y$	
	$= 0.9 x 20 x 350 x 300$	
	$= 1890.0$ kN	
	$T_r = C_r > T_u = C_u = 171$ kN	
SABS162-1:. Table 3	**Shear:**	
	a) $V_r = 0.67 \phi_w A_w f_{uw}$	
	$= 0.67 x 0.67 x 20 x 350 x 480$	
	$= 1508.3$ kN	
	b) $V_r = 0.67 \phi A_w f_y$	
	$= 0.67 x 0.9 x 20 x 350 x 300$	
	$= 1266.3$ kN	
	$V_r > V_u = 0.855$ kN	
C.2.3.4.	<u>Hinge Bolts:</u>	
	Use 6 M30 Grd 8.8 Bolts	
SABS162-1: §13.11.3	<u>1. Tension:</u>	
	$T_r = 0.75 \phi_b A_b f_u$	
	$= 0.75 x 0.67 x 707 x 800$	
	$= 284$ kN/Bolt	
	$T_r > T_u = 684/4 = 171$ kN	

SABS162-1: Table 6, §22.8

2. Layout:

Minimum Edge Distance = 1.4d

= 1.4x30

= 42mm

Edge Distance = 45 mm > Minimum Edge Distance

C.2.3.5.

Pin:

For Member forces refer to Figure C. 34.

Use pin with diameter = 50 mm

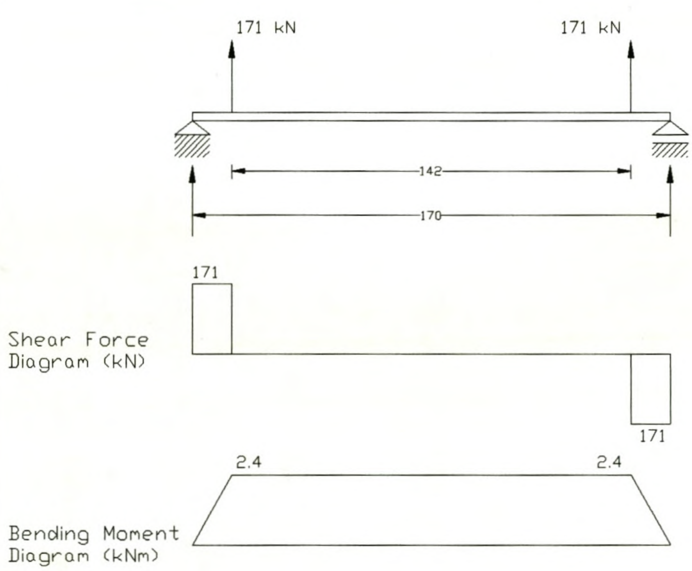


Figure C. 34. Pin design: Shear Force and Bending Moment Diagrams

SABS162-1:. §13.11.2	<u>1. Shear:</u> $V_r = 0.6\phi_b A_b f_u$ $= 0.6x0.67x3.14x50^2/4x450$ $= 35.2$ kN	
SABS162-1:. §13.5	<u>2. Moment:</u> $M_r = \phi z_e f_y$ $= 0.9x3.14x25^3/4x300$ $= 3.3$ kN	
SABS162-1:. Table 6, §22.8	<u>3. Layout:</u> Pin: Minimum Edge Distance = 1.5d = 1.5x50 = 75 mm Bush: Minimum Edge Distance = 1.5d = 1.5x55 = 82.5 mm Edge Distance = 83 mm > Minimum Edge Distance	
C.2.3.6.	<u>Hinge Fixing Bracket:</u> The Hinge Fixing Bracket is drawn in Figure C. 35. <u>Across Bracket:</u> <u>Properties:</u> L = 122 mm	
SABS 0162-1: §13.4.2	<u>1. Shear:</u> $V_r = \phi 0.66Afy$ $= 0.9x0.66x20x680x300$ $= 2\ 423.5$ kN $V_r > V_u = 171$ kN	

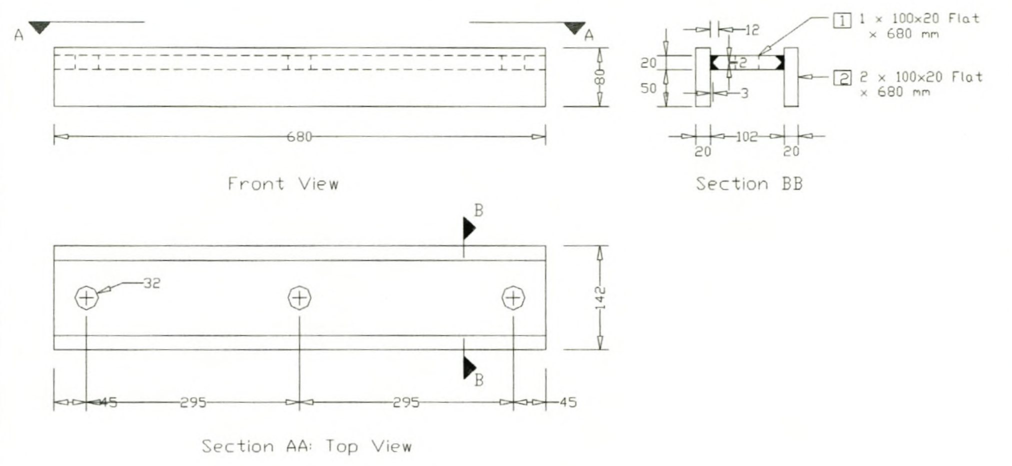


Figure C. 35. Hinge Fixing Bracket

SABS 0162-1: §13.5 (a)

2. Bending:

$M_r = \phi z_e f_y$

$= 0.9x1/6x20^2x680x300$

$= 12.2$ kN

$M_r > M_u = 10.43$ kN

Along Bracket:

Properties:

L	= 2 x 295 mm	A	= 5240 mm^2
$\bar{y}$	= 31.6 mm	I	= 1 899.2x10^3 mm^4

SABS 0162-1: §13.4.2

1. Shear:

$V_r = \phi 0.66Afy$

$= 0.9x0.66x5240x300$

$= 933.5$ kN

$V_r > V_u = 102.9$ kN

SABS 0162-1: §13.5 (a)	**2. Bending:** $M_r = \phi z_e f_y$ $= 0.9x(1\ 899.2x10^2/43.9)x300$ $= 11.6$ kN $M_r > M_u = 5.55$ kN	

C.2.4. Design: Supports

The Supports consist of a horizontal support bridge and a vertical support. Refer to drawings 04-3D-01, 04-01/1, 04-01/2, 04-02/1 and 04-02/2 for more detail on the supports.

C.2.4.1. Loading and Serviceability:

See Section C.1., Figure C. 36

- Loading on supports:

  Load case 1:

  600kN Vertical (hydraulic actuator at centre of loading bridge).

  Load case 2:

  End reaction not to exceed 684 kN Vertical and 200 kN horizontal as this will cause the capacity of the test floor to be exceeded

- Serviceability of supports:

  Deflections of the supports will have to be negligible compared to the deflections of the test specimen.

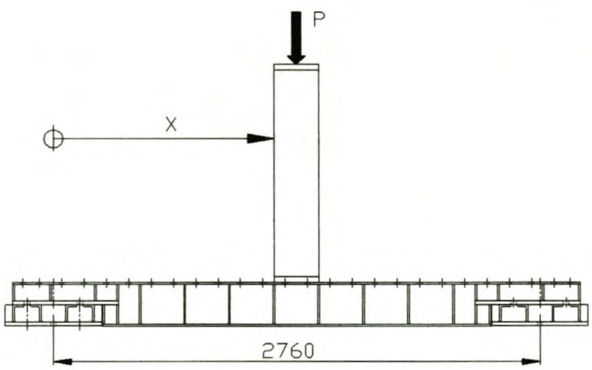


Figure C. 36. Loading on the supports

	Due to the flexibility of the supports, the supports can be made stiffer or the capacity increased by using two supports together. For this reason the capacity and deflection for a single support be calculated.	
C.2.4.2.	<u>Horizontal Support Bridge Design:</u>	
SASCH Table 5.4:	1. <u>Bending:</u> For unsupported length < 3m $M_r = 267$ kNm (Note: bending is only applicable with P is upward)	
SABS 162-1 §13.4.1.1. (a)	2. <u>Shear:</u> End Section: $h_w/t_w = 94/8.6 = 10.9 < 440\sqrt{(k_v/f_y)} = 58.7$ (assume no web stiffeners, $k_v = 5.34$) $V_r = \phi A_v f_{vu}$ $= 0.9 \times 94 \times 8.6 \times 0.66 \times 300$ $= 134$ kN Centre Section: $h_w/t_w = 225.6/8.6 = 26.2 < 440\sqrt{(k_v/f_y)} = 58.7$ (no web stiffeners, $k_v = 5.34$) $V_r = \phi A_v f_{vu}$ $= 0.9 \times 225.6 \times 8.6 \times 0.66 \times 300$ $= 345.7$ kN	
SABS 162-1 §15.9.	3. <u>Web yield and crippling:</u> a. Interior loads: Bearing length: N = 254 mm	

	1. $B_r = 1.10\phi t_w(N + 5k)f_y$ $= 1.10x0.9x8.6x(254 + 5x27.1)x300$ $= 994.8$ kN 2. $B_r = 300\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$ $= 300x0.9x8.6^2\{1+3(254/254)(8.6/14.2)^{1.5}\}\sqrt{(300x8.6/14.2)}$ $= 1072.4$ kN b. End Reactions: Not applicable (3 mm Pack plate would be required for down ward loading at end)	
SABS 162-1 §13.11.3	4. End Bolts: Use 4 M24 Grade 8.8 Bolts T_r (four bolts) $= 0.75\phi_b n A_b f_u$ $= 0.75x0.67x4x452x800$ $= 726.8$ kN > 684 kN	
Structural Steelwork Connections, (12.2)	5. Base Plate: Minimum base thickness to mach capacity of bolts: bending caused by bolt in tension: $M_u = 684/4x(130/2-12.7-8.6/2)$ $= 8.2$ kNm Average effective length of plate: $l_e = 442$ mm (Determined graphically assume 30° load dispersion unto web stiffeners) $t_p = \sqrt{(6M_u/0.9l_e f_y)}$ $= \sqrt{(6x8.2x10^3/0.9x442x300)}$ $= 20$ mm	
SAISC Structural Steelwork Connections, (12.1)	6. Bearing unto Reinforced Concrete Floor slab: (Refer to Figure C. 37) $B_r = 0.4f_{cu} = 8$ MPa Area $= 254x1098 = 278.9x10^3$ mm^2 $\sigma_b = F/A$ $= 2.45$ MPa	

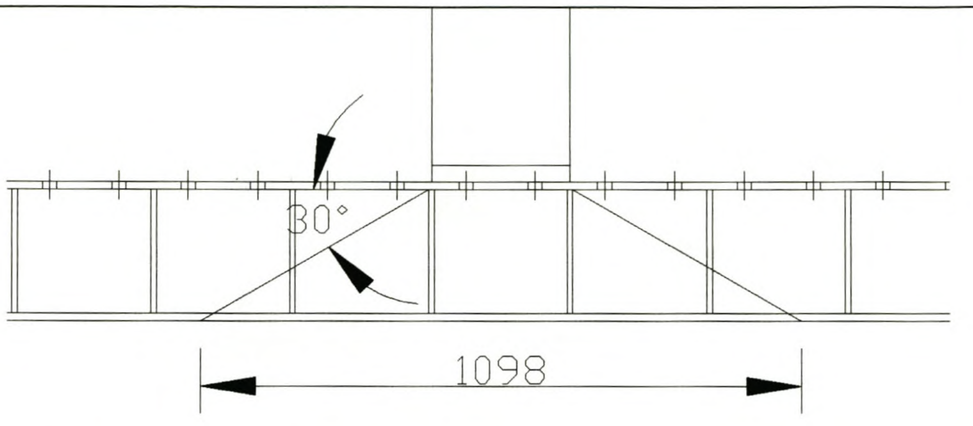


Figure C. 37. Bearing unto Floor Slab

SABS 162-1
§15.6.2

6. Stiffeners:

Stiffeners ensure direct bearing unto test floor.

Design b_v = 90 mm

$b_v/t_v < 200/\sqrt{f_y}$

Therefore t_v = 8 mm

Web Length = $25t_w$ = 25x8.6 = 215 mm < 254 mm

Stiffener Properties:

Area = 2x90x8 + 215x8.6 = 3286 mm^2

$I_{xx} = 215 \times 8.6^3/12 + 2 \times 8 \times 90^3/12 + 2 \times 90 \times 8 \times (45+8.6)^2$

$= 5.12 \times 10^6\ mm^2$

Rxx = $\sqrt{I_{xx}/A}$ = 39.5

Le = 0.75x(254 – 2x14.2) = 169.2 mm

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§113.3

$\lambda = kL/r\sqrt{(f_y/\pi^2 E)} = 169.2/39.5 \times \sqrt{(300/3.14^2 \times 200 \times 10^3)} = 0.052$

$C_r = \phi A f_y$

$= 0.9 \times 3286 \times 300$

= 887.2 kN / stiffener

(Note: two stiffeners loaded at a time, therefore Cr = 1774. 4 kN)

7. Capacity Envelope for the Support Bridge:

The Capacity envelope for the Support bridge is shown in Figure C. 38.

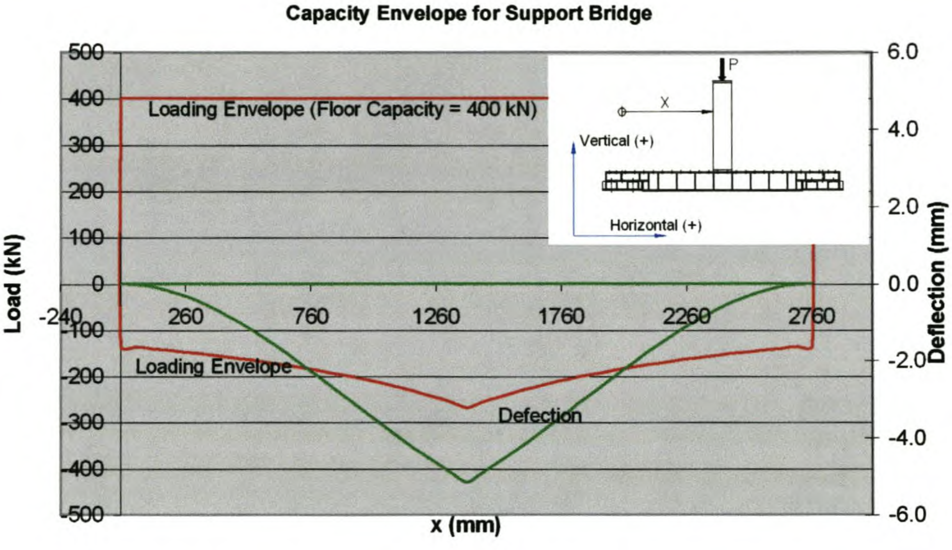


Figure C. 38. Capacity Envelope for Support Bridge

C.2.4.3. <u>Vertical Support Design:</u>

Similar to the support bridge, the load was iterated to determine the maximum capacity of the vertical support using Prokon software. The loading capacity for the vertical support is shown in Figure C. 39, Figure C. 40, Figure C. 41, Figure C. 42, Figure C. 43 and Figure C. 44. The design files and Excel files with the capacity values for the support are on the CD rom accompanying the thesis.

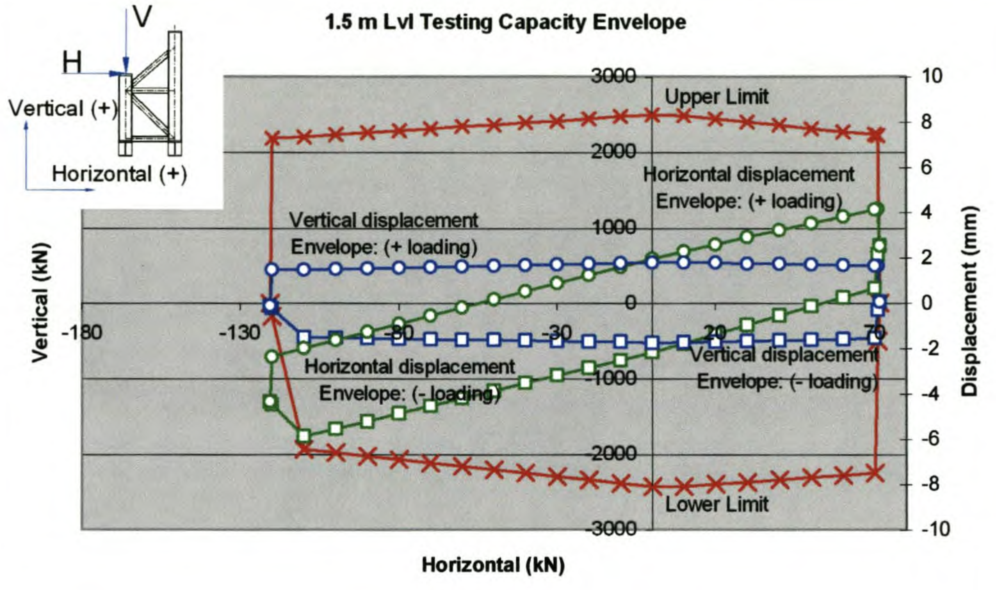


Figure C. 39. 1.5 m Lvl Support Capacity Envelope: Vertical Load

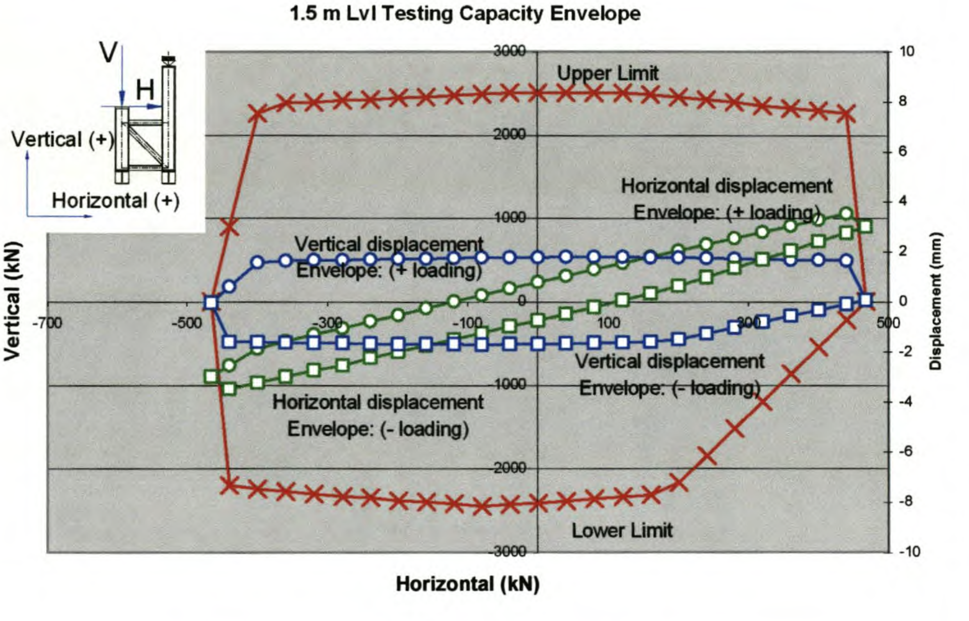


Figure C. 40. 1.5 m Lvl Support Capacity Envelope: Vertical and Horizontal Loads

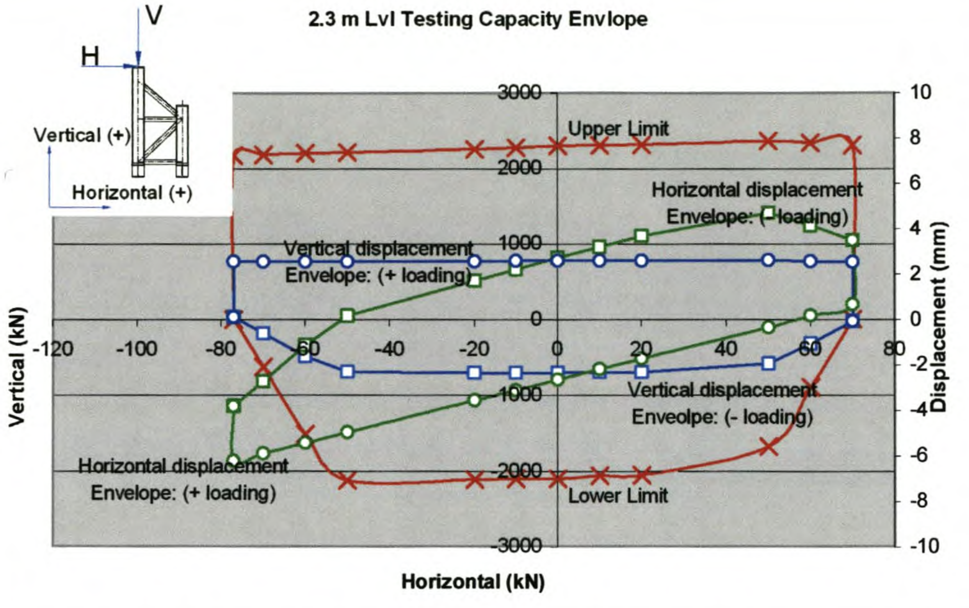


Figure C. 41. 2.3 m Lvl Support Capacity Envelope: Vertical Loads

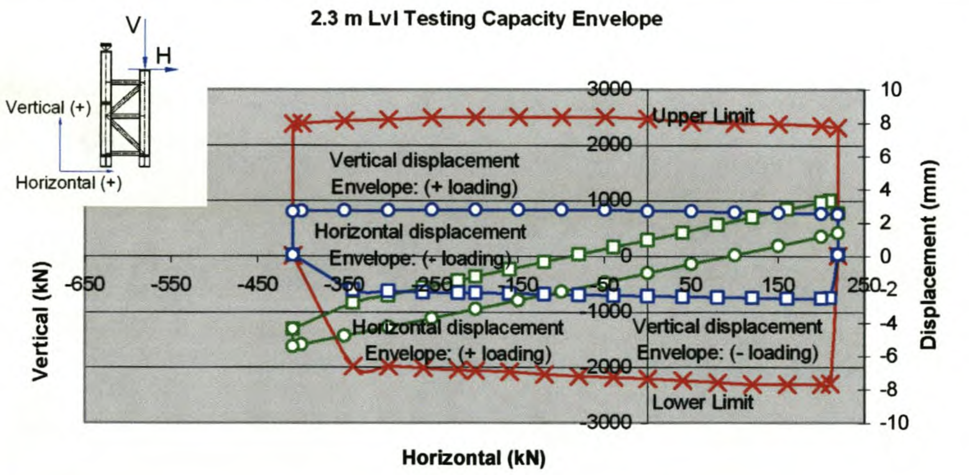


Figure C. 42. 2.3 m Lvl Support Capacity Envelope: Vertical and Horizontal Loads

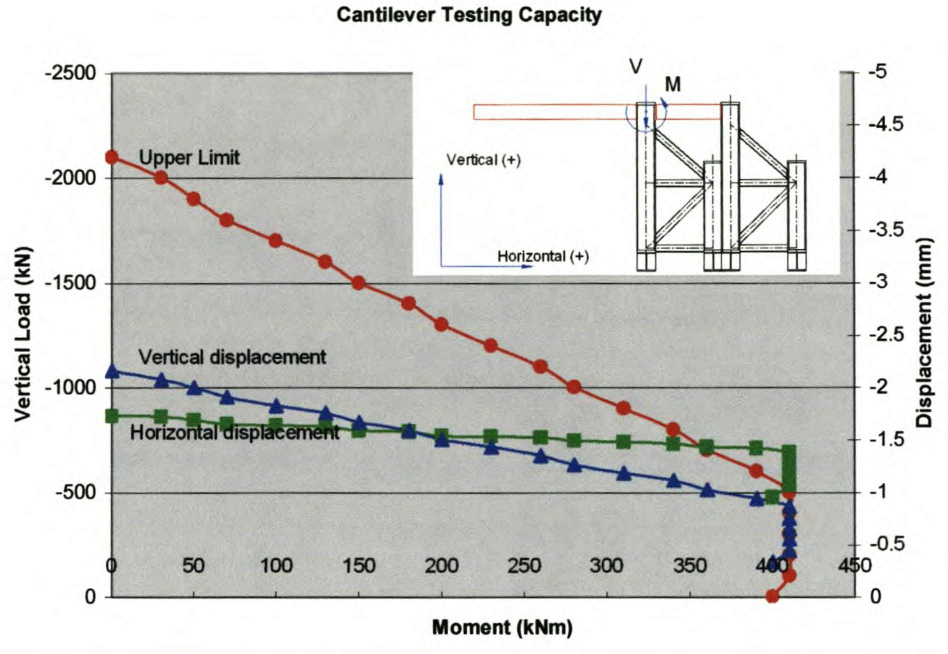


Figure C. 43. Support Capacity for Cantilever Testing: Displacement of Support

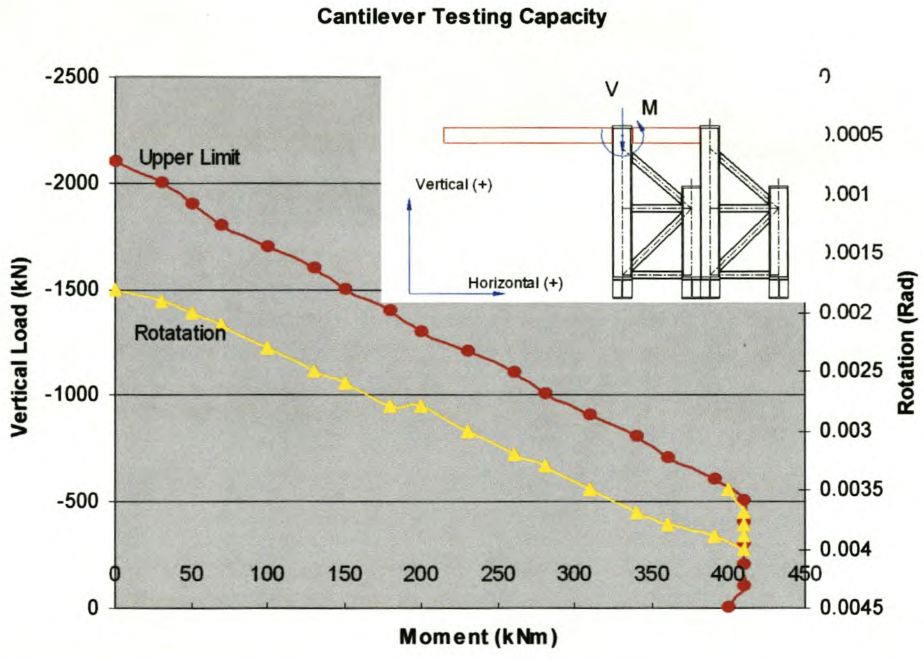
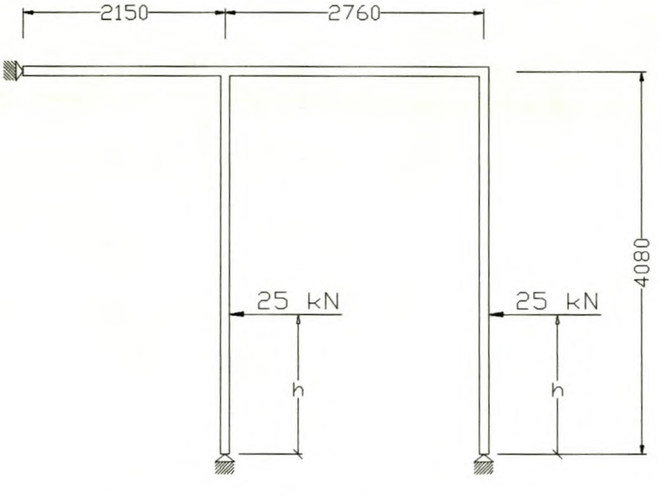


Figure C. 44. Support Capacity for Cantilever Testing: Rotation of Support

C.2.5.	Design: Lateral Supporting Frame	
	The lateral supporting frames are used to provide lateral support to the supporting mechanism. Refer to drawings Figure C. 46, 05-3D-01, 05-01/1, 05-01/2 for more detail on the supports frame and to 05-3D-02, 05-3D-03, 5-3D-04, 05-02/1, 05-03/1 and 05-04/1 2 for more detail on the connectors.	
C.2.5.1.	Loading and Serviceability:	
Refer to Figure C. 45	• Extreme load case: • Load case 1 Horizontal Load = -25 kN / column at h = 1.492 m Deflections of the frame will have to be negligible compared to the deflections of the test specimen to ensure effective lateral support.	
		
	Figure C. 45 Loading on Lateral Supporting Frame: Horizontal Loading at height h.	

C.2.5.2 **Properties**

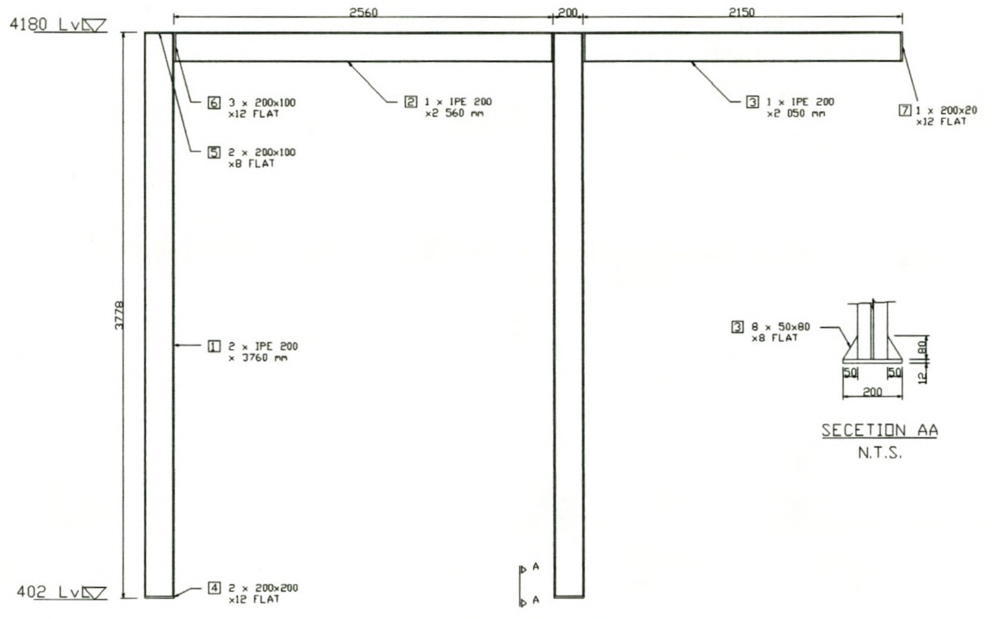


Figure C. 46 Lateral Supporting Frame

Geometry:

Portal frame,

L = 2760 mm

h = 4080 mm

The supporting frame is shown in Figure C. 46.

C.2.5.2	**Frame Design:**	
	Section Design:	
	Profile class:	

	$b1/t$	
Flanges of I sections:	$100/2x8.5 = 5.88$	$b1/t < 145/\sqrt{f_y} = 8.372$ Class 1
Web:	$83/5.6 = 14.86$	$b1/t < 1100/\sqrt{f_y} = 63.5$ Class 1

SABS 162-1 Table 1

Section class: 1 — Class 1

SABS 162-1 §13.4.1.1. (a)

1. Shear:

$h_w/t_w = 159/5.6 = 28.4 < 440\sqrt{(k_v/f_y)} = 58.7$

(no web stiffeners, $k_v = 5.34$)

$$V_r = \phi A_v f_{vu}$$
$$= 0.9 \times (200-2x8.5) \times 5.6 \times 0.66 \times 300$$
$$\mathbf{= 182.6\ kN}$$

$$V_r > V_u = 36.3\ kN$$

SABS 162-1 §13.6.

2. Bending:

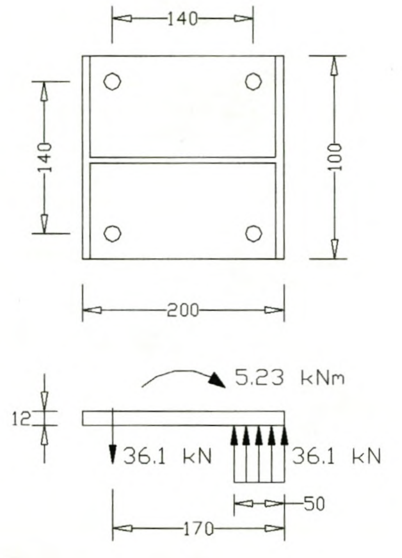
$$M_{cr} = \varpi_2\pi/KL\ \sqrt{[EI_yGJ + (\pi E/KL)^2 I_y C_w]}$$

$EI_yGJ = 200x10^3 x1.42x10^6 x77x10^3 = 1.535x10^{21}$

$(\pi E/KL)^2 I_y C_w = (\pi x200x10^3/1.44/4080)^2 x1.42x10^6 x13.1x10^9$

$$= 2.128x10^{20}$$

	$\varpi_2 = 1.0$ $M_{cr} = 1x\pi/1.44/4080\ \sqrt{[1.535x10^{21} + 2.128x10^{20}]}$ $= 22.35$ kNm $M_p = z_{pl}f_y = 66.3$ kN $0.67M_p = 44.4$ kNm $> M_{cr}$ $M_r = \phi M_{cr}$ $= 0.9x22.35$ $= 20.1$ kNm $M_r > M_u = 19.5$ kNm	
SABS 162-1 §15.9.	3. Web yield and crippling: Bearing length: N = 50 mm a. Interior loads: 3. $B_r = 1.10\phi t_w(N + 5k)f_y$ $= 1.10x0.9x5.6x(50 + 5x20.5)x300$ $= 253.6$ kN 4. $B_r = 300\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$ $= 300x0.9x5.6^2\{1+3(50/200)(5.6/8.5)^{1.5}\}\sqrt{(300x5.6/8.5)}$ $= 253.2$ kN b. End Reactions: 3. $B_r = 1.10\phi t_w(N + 2.5k)f_y$ $= 1.10x0.9x5.6x(50 + 2.5x20.5)x300$ $= 168.4$ kN 4. $B_r = 150\phi t_w^2\{1+3(N/h)(t_w/t_f)^{1.5}\}\sqrt{(f_y t_f/t_w)}$ $= 150x0.9x5.6^2\{1+3(50/200)(5.6/8.5)^{1.5}\}\sqrt{(300x5.6/8.5)}$ **= 126.6 kN**	

C.2.5.2	**Column/Base Connection: Base Plate Design:**	
		
	Figure C. 47. Base plate & holding down bolts design.	
SAISC Structural Steelwork Connections, (12.4)	Refer to Figure C. 47 for forces on base plate $M_u - (bd_2\sigma_b)(d_1\text{-}d_2/2) = 0$ Use d_2 = 50 mm $\Rightarrow$ σ_b = 3.61 MPa $T_u = C_u = \sigma_b A_b$ = 3.61x200x50 = 36.1 kN	
SABS 162-1 1999 §13.11.3	Use 4 M16 Grade 8.8 Bolts T_r (two bolts) $= 0.75\phi_b n A_b f_u$ = 0.75x0.67x2x201x800 = 161.6 kN	

§13.11.2(b).	V_r (two bolts) $= 0.6\phi_b n A_b f_u$ $= 0.6x0.67x2x0.75x201x800$ $= 97.0$ kN	
§13.11.4.	$V_u/V_r + T_u/T_r = 13.1/97.0 + 36.1/161.6 = 0.213 < 1.4$ Bolt combination sufficient	
SAISC Structural Steelwork Connections, (12.2)	Minimum base thickness with a = 50-8 -6 = 36 mm: $t_p = \sqrt{(3\sigma_b\, a^2/0.9f_y)}$ $= \sqrt{(3x3.6x36^2/0.9x300)}$ $= 7.2$ mm Minimum base thickness: downward bending caused by bolt in tension: $M_u = (36.1/2)x(30-5-8/2)$ $= 0.288$ kNm effective length of plate (assume 30° load dispersion): $l_e = 55.4$ mm $t_p = \sqrt{(6M_u/0.9l_e f_y)}$ $= \sqrt{(6x0.288x10^3/0.9x55.4x300)}$ $= 10.7$ mm $t = 12$ mm $> t_p = 10.7$ mm	
C.2.5.3	<u>Column/Beam Connection:</u> Refer to Figure C. 48 for forces. End Plate: Moments taken about tension bolts: $M_u + C_u.c - (bd_2\sigma_b)(d_1-d_2/2) = 0$ With $d_2 = 8.6$ mm $\Rightarrow \sigma_b = 125.23$ MPa	

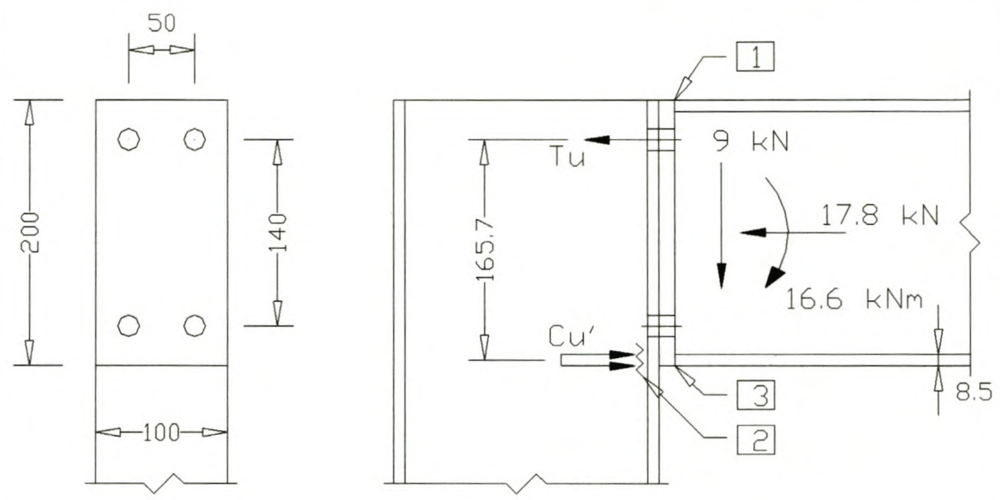


Figure C. 48. Bolted column to beam moment connection.

$T_b = \sigma_b A_b - C_u$

$= 125.23x100x8.6 - 17.8x10^3$

$= 89.9$ kN

SABS 162-1 §13.11.3	Use 4 M16 Grade 8.8 Bolts
	T_r (two bolts) $= 0.75\phi_b n A_b f_u$
	$= 0.75x0.67x2x201x800$
	$= 161.6$ kN
§13.11.2(b).	V_r (two bolts) $= 0.6\phi_b n A_b f_u$
	$= 0.6x0.67x2x0.75x201x800$
	$= 97.0$ kN
§13.11.4.	$V_u/V_r + T_u/T_r = 9.0/97.0 + 89.9/161.6 = 0.649 < 1.4$
	Bolt combination sufficient
SAISC Structural Steelwork Connections, (7.37)	Minimum base thickness: downward bending caused by bolt in tension: (Plate is bent in double curvature)
	$t_p = \sqrt{(1.5T_u'm/\phi 9 l_1 f_y)}$
	where $m = (g - t_{wb} - 2e) = 17.2$ mm
	$l_1 = p_b + 3.5m = 60.2$ mm
	$e = 5$ mm

	$\phi = 0.9$ $t_p = \sqrt{(1.5x89.9x10^3x17.2/0.9x60.2x300)}$ $= 11.9$ mm $t = 12$ mm $> t_p = 11.9$ mm	
	1. Welding:	
	Use E70XX electrodes, 6 mm fillet weld	
SABS162-1: Table 3	a) $V_r = 0.67\phi_w A_w f_{uw}$ $= 0.67x0.67x(6/\sqrt{2})x100x480$ $= 91.4$ kN b) $V_r = 0.67\phi A_w f_y$ $= 0.67x0.9x10x100x300$ $= 180.9$ kN $V_r > V_u = 89.9$ kN	
SABS 162-1 §15.9.	**2. Web yield and crippling:** $B_r = 1.10\phi t_{wc}(t_{fb} + t_p + 5k_c)f_y$ $= 1.10x0.9x5.6x(8.5 + 12 + 5x20.5)x300$ $= 186.0$ kN $B_r > C_u' = 107.7$ kN	
SABS 162-1 1999 §15.9.	**3. Welding:** $C_r = 7\phi f_y t_{fc}^2$ $= 7x0.9x300x8.5^2$ $= 136.6$ kN $C_r > C_u' = 107.7$ kN	
SABS 162-1 1999 §15.9.	**4. Shear:** $V_r = 182.6$ kN $> C_u' = 107.7$ kN	

C.2.5.4

Beam/4.080 lvl Connection:

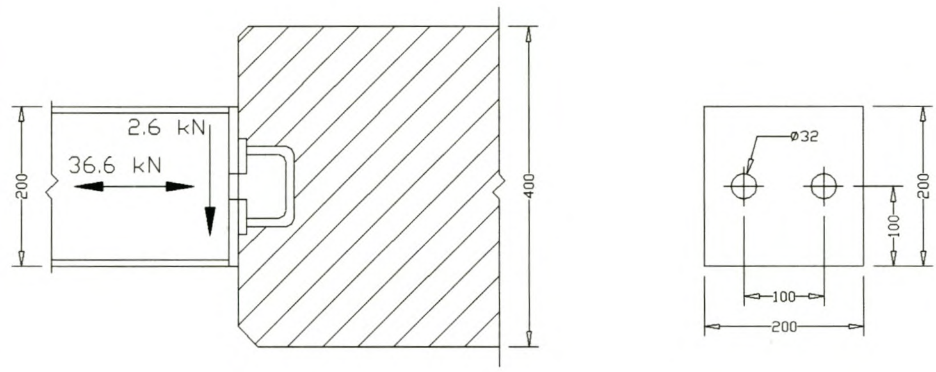


Figure C. 49. Bolted beam to tracks at 4.080 lvl.

Refer to Figure C. 49 for forces.

1. End Plate:

M_u = 36.3x103x100/4

= 0.908 kNm

M_r = $\phi z_e f_y$

= $0.9 \times 12^2 \times 200/6 \times 300$

= 0.908 kNm

SABS 162-1

Use 2 M30 Grade 8.8 Bolts

§13.11.3

T_r (two bolts) = $0.75\phi_b n A_b f_u$

= 0.75x0.67x2x707x800

= 528.4 kN

§13.11.2(b).

V_r (two bolts) = $0.6\phi_b n A_b f_u$

= 0.6x0.67x2x0.75x707x800

= 341.1 kN

§13.11.4.

$V_u/V_r + T_u/T_r$ = 2.6/341.1 + 36.3/528.4 = 0.076 < 1.4

Bolt combination sufficient

C.2.5.5.	<u>Frame Design:</u> Refer to Figure C. 50, Figure C. 52 and Figure C. 51 for the load capacity envelope of the lateral support

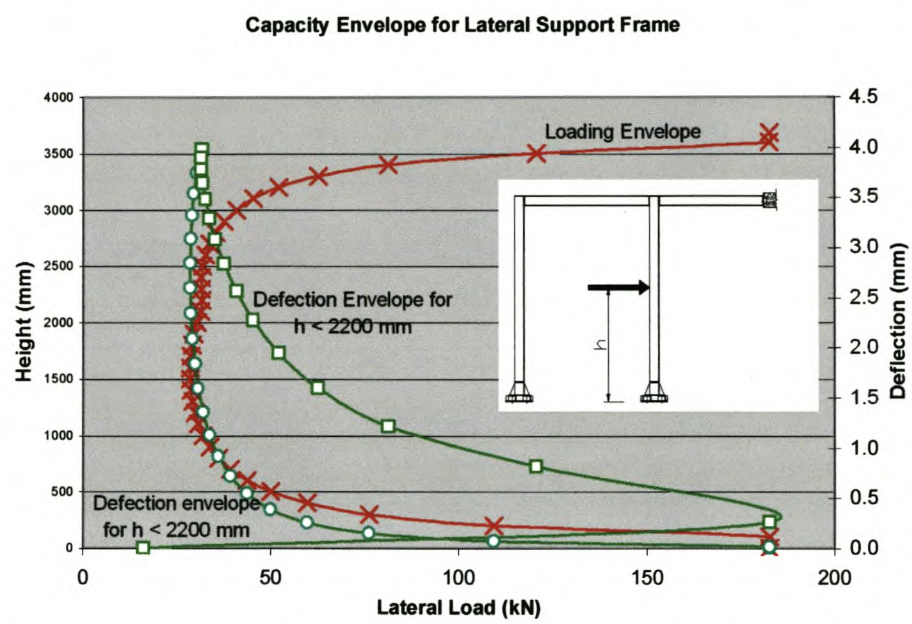


Figure C. 50. Capacity Envelope of the Lateral Support Frame

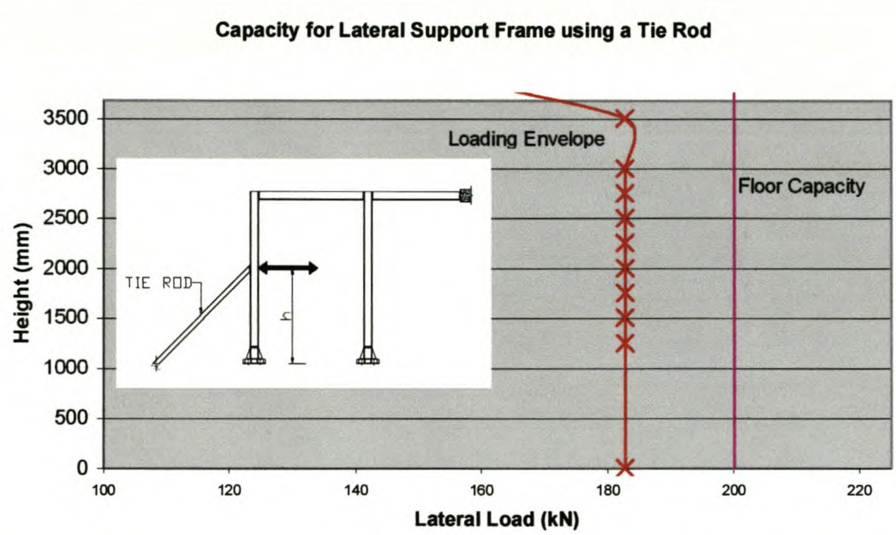


Figure C. 51. Capacity of the Lateral Support Frame using a Tie Rod

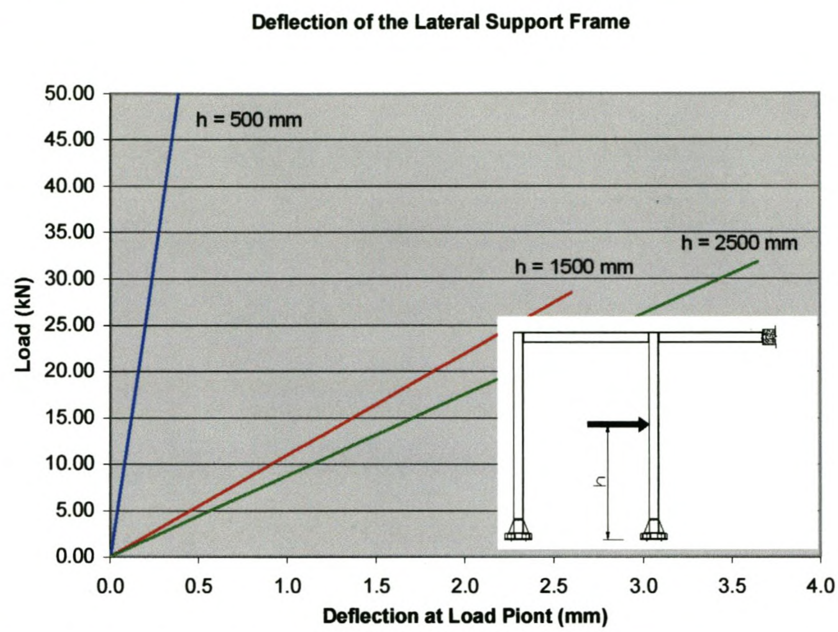


Figure C. 52. Deflection of the Lateral Support Frame

C.2.5.6	<u>Connector (Type B) Design:</u> Refer to drawings 05-3D-02 and 05-02/1 for more detail on the connector. Minimum Properties of Column: $A = 3600\ mm^2$ $I_{xx} = 22.68x10^3\ mm^4$ $\quad r_{xx} = 79.4\ mm$ $I_{yy} = 1.35x10^3\ mm^4$ $\quad r_{yy} = 19.4\ mm$ <u>1. Bending:</u>	
SABS162-1: §13.1	$M_r = \phi z_e f_y$ $M_{xx} = 21.43\ kNm$ $\quad M_{yy} = 5.24\ kNm$ $M_r > M_u = 5.23\ kNm$ <u>2. Axial Loading:</u>	
SABS162-1: §13.3	$\lambda = kL/r \sqrt{(f_y/\pi^2 E)} = 0.180$ $C_r = \phi A f_y (1+\lambda^{2n})^{-1/n}$ $= 0.9x3600x300(1+0.180^{2x1.34})^{-1/1.34}$ $= 964.7\ kN$ $C_r > C_u$ <u>3. Top base Plate:</u> The design of the top base plate is the same as for column base plate. Refer to C.2.5.2. and Figure C. 47.	

	4. Bottom Base Plate:	
SAISC Structural Steelwork Connections, (12.4)	$M_u - (bd_2\sigma_b)(d_1 - d_2/2) = 0$ Use $d_2 = 100$ mm $\Rightarrow \quad \sigma_b = 1.05$ MPa $T_u = C_u = \sigma_b A_b$ $= 1.05 \times 200 \times 100$ $= 20.9$ kN	
SABS 162-1 §13.11.3	Use 4 M30 Grade 4.8 Bolts T_r (two bolts) $= 0.75\phi_b n A_b f_u$ $= 0.75 \times 0.67 \times 2 \times 707 \times 420$ $= 298.4$ kN	
§13.11.2(b).	V_r (two bolts) $= 0.6\phi_b n A_b f_u$ $= 0.6 \times 0.67 \times 2 \times 0.75 \times 707 \times 420$ $= 179.1$ kN	
§13.11.4.	$V_u/V_r + T_u/T_r = 13.1/179.1 + 20.9/298.4 = 0.143 < 1.4$ Bolt combination sufficient	
SAISC Structural Steelwork Connections, (12.2)	Minimum base thickness with a = 100 - 8/2 = 96 mm: $t_p = \sqrt{(3\sigma_b a^2/0.9f_y)}$ $= \sqrt{(3 \times 1.05 \times 96^2/0.9 \times 300)}$ $= 10.4$ mm Minimum base thickness: downward bending caused by bolt in tension: $M_u = (20.9/2) \times (50 - 10/2 - 5)$ $= 0.418$ kNm effective length of plate (assume 30° load dispersion): $l_e = 119.2$ mm	

$t_p = \sqrt{(6M_u/0.9l_e f_y)}$

$= \sqrt{(6x0.418x10^6/0.9x119.2x300)}$

$= 8.8$ mm

$t = 12$ mm $> t_p = 10.4$ mm

5. Welding Column Plates & Base Plates:

Welding fillet 5 mm thick all round.

(Use E70XX electrodes)

SABS162-1: Table 3

6. Shear:

a) $V_{r\,min} = 0.67\phi_w A_w f_{uw}$

$= 0.67x0.67x(5/\sqrt{2})x2x(2x100+200)x480$

$= 609.4$ kN

b) $V_r = 0.67\phi A_m f_y$

$= 0.67x0.9x(5/\sqrt{2})x2x(2x100+200)x300$

$= 511.7$ kN

$V_r > V_u = 13.1$ kN

C.2.5.7. **Connector (Type C) Design:**

Refer to drawings 05-3D-03 and 05-02/1 for more detail on the connector.

Minimum Properties of Column:

$A = 3600\ mm^2$

$I_{xx} = 22.68x10^3\ mm^4$ $r_{xx} = 79.4\ mm$

$I_{yy} = 1.35x10^3\ mm^4$ $r_{yy} = 19.4\ mm$

1. Bending:

SABS162-1: §13.1

$M_r = \phi z_e f_y$

$M_{xx} = 21.43\ kNm$ $M_{yy} = 5.24\ kNm$

$M_r > M_u = 5.23\ kNm$

2. Axial Loading:

SABS162-1: §13.3

$\lambda = kL/r\ \sqrt{(f_y/\pi^2 E)} = 0.093$

$C_r = \phi A f_y (1+\lambda^{2n})^{-1/n}$

$= 0.9x3600x300(1+0.093^{2x1.34})^{-1/1.34}$

$= 970.8\ kN$

$C_r > C_u$

3. Top Base Plate:

The design of the top base plate is the same as for column base plate. Refer to C.2.5.2. and Figure C. 47.

	4. Bottom Base Plate:	
SAISC Structural Steelwork Connections, (12.4)	$M_u - (bd_2\sigma_b)(d_1 - d_2/2) = 0$ Use $d_2 = 100$ mm $\Rightarrow \quad \sigma_b = 0.62$ MPa $T_u = C_u = \sigma_b A_b$ $= 0.62 \times 254 \times 100$ $= 15.68$ kN	
SABS 162-1 §13.11.3	Use 4 M24 Grade 4.8 Bolts T_r (two bolts) $= 0.75\phi_b n A_b f_u$ $= 0.75 \times 0.67 \times 2 \times 452 \times 420$ $= 190.8$ kN	
§13.11.2(b).	V_r (two bolts) $= 0.6\phi_b n A_b f_u$ $= 0.6 \times 0.67 \times 2 \times 0.75 \times 452 \times 420$ $= 114.5$ kN	
§13.11.4.	$V_u/V_r + T_u/T_r = 13.1/114.5 + 15.7/190.8 = 0.197 < 1.4$ Bolt combination sufficient	
SAISC Structural Steelwork Connections, (12.2)	Minimum base thickness with a = (420-200-8)/2 = 106 mm: $t_p = \sqrt{3\sigma_b a^2/0.9f_y}$ $= \sqrt{3 \times 0.62 \times 106^2/0.9 \times 300}$ $= 8.77$ mm Minimum base thickness: downward bending caused by bolt in tension: $M_u = (15.68/2) \times 211$ $= 0.599$ kNm effective length of plate (assume 30° load dispersion): $l_e = 127$ mm	

	$t_p = \sqrt{(6M_u/0.9l_ef_y)}$ $= \sqrt{(6x0.599x10^6/0.9x127x300)}$ $= 10.24$ mm $t = 12$ mm $> t_p = 10.24$ mm **5. Welding Column Plates & Base Plates:** Welding as for Connector (Type C): fillet 5 thick all round. (Use E70XX electrodes)	
SABS162-1: Table 3	**6. Shear:** a)$V_{r\,min} = 0.67\phi_w A_w f_{uw}$ $= 0.67x0.67x(5/\sqrt{2})x2x(2x100+200)x480$ $= 609.4$ kN b) $V_r = 0.67\phi A_m f_y$ $= 0.67x0.9x(5/\sqrt{2})x2x(2x100+200)x300$ $= 511.7$ kN $V_r > V_u = 13.1$ kN	

C.2.5.8.	Connector (Type D) Design: Refer to drawings 05-3D-04 and 05-02/1 for more detail on the connector Minimum Properties of Column: $A = 3600\ mm^2$ $I_{xx} = 22.68x10^3\ mm^4$ $\quad$ $r_{xx} = 79.4\ mm$ $I_{yy} = 1.35x10^3\ mm^4$ $\quad$ $r_{yy} = 19.4\ mm$ 1. Bending:	
SABS162-1: §13.1	$M_r = \phi z_e f_y$ $M_{xx} = 21.43\ kNm$ $\quad$ $M_{yy} = 5.24\ kNm$ $M_r > M_u = 5.23\ kNm$ 2. Axial Loading:	
SABS162-1: §13.3	$\lambda = kL/r\ \sqrt{(f_y/\pi^2 E)} = 0.064$ $C_r = \phi A f_y (1+\lambda^{2n})^{-1/n}$ $= 0.9x3600x300(1+0.064^{2x1.34})^{-1/1.34}$ $= 971.5\ kN$ $C_r > C_u$ 3. Top Base Plate: The design of the top base plate is the same as for column base plate. Refer to C.2.5.2. and Figure C. 47.	

	4. Bottom Base Plate:	
SAISC Structural Steelwork Connections, (12.4)	$M_u - (bd_2\sigma_b)(d_1\text{-}d_2/2) = 0$ Use $d_2 = 100$ mm $\Rightarrow \quad \sigma_b = 0.44$ MPa $T_u = C_u = \sigma_b A_b$ $= 0.44\text{x}400\text{x}100$ $= 17.43$ kN	
SABS 162-1 §13.11.3	Use 4 M30 Grade 4.8 Bolts T_r (two bolts) $= 0.75\phi_b n A_b f_u$ $= 0.75\text{x}0.67\text{x}2\text{x}707\text{x}420$ $= 298.4$ kN	
§13.11.2(b).	V_r (two bolts) $= 0.6\phi_b n A_b f_u$ $= 0.6\text{x}0.67\text{x}2\text{x}0.75\text{x}707\text{x}420$ $= 179.1$ kN	
§13.11.4.	$V_u/V_r + T_u/T_r = 13.1/179.1 + 17.43/298.4 = 0.131 < 1.4$ Bolt combination sufficient	
SAISC Structural Steelwork Connections, (12.2)	Minimum base thickness with a = 100-5 = 95 mm: $t_p = \sqrt{(3\sigma_b\, a^2/0.9f_y)}$ $= \sqrt{(3\text{x}0.44\text{x}95^2/0.9\text{x}300)}$ $= 6.6$ mm Minimum base thickness: downward bending caused by bolt in tension: $M_u = (17.43/2)\text{x}140$ $= 1.22$ kNm effective length of plate (assume 30° load dispersion): $l_e = 200$ mm	

	$t_p = \sqrt{(6M_u/0.9l_e f_y)}$ $= \sqrt{(6x1.22x10^6/0.9x200x300)}$ $= 11.64$ mm $t = 12$ mm $> t_p = 11.46$ mm 5. Welding Column Plates & Base Plates: Welding as for Connector (Type C): fillet 5mm thick all round. (Use E70XX electrodes)	
SABS162-1: Table 3	6. Shear: a) $V_{r\,min} = 0.67\phi_w A_w f_{uw}$ $= 0.67x0.67x(5/\sqrt{2})x2x(2x100+200)x480$ $= 609.4$ kN b) $V_r = 0.67\phi A_m f_y$ $= 0.67x0.9x(5/\sqrt{2})x2x(2x100+200)x300$ $= 511.7$ kN $V_r > V_u = 13.1$ kN	

APPENDIX D

This appendix contains a summary of the size and loading capacity of the MTA. For more details on the design and the restrictions on the size refer to appendix C and chapter 3 respectively.

D.1. Size Restrictions of the MTA

Minimum	**Single Span (m)**	**Multi-span (m)**	**Height (m)**	**Width (m)**
Minimum	2	2x2	-	-
Maximum				
Normal Set up	10	2x5	1.5	2.7
Rotated Set up	20	2x10	1.5	2.7

Table D.1. Maximum and Minimum Sizes for Test Specimen

D.2. Loading Capacity of the MTA

D.2.1. Test Floor Capacity

	Maximum Load (kN)
Vertical	400 kN at 4 920 c/c for 4 points
Horizontal	200 kN at 4 920 c/c for 4 points

Table D.2. Test Floor Capacity

D.2.2. Track Capacity

The applied loads on the track should not cause the reaction at any fixing point to exceed the loading as given above in D.2.1. The Loading Envelope of a track is given in Figure D.1.

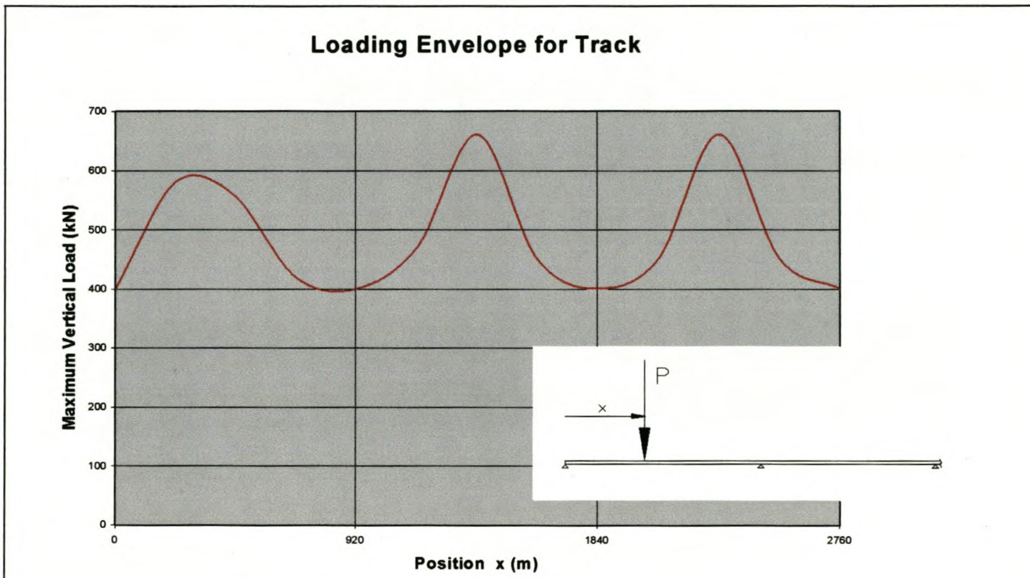


Figure D.1. Loading Envelope for a Track

D.2.3. Loading Bridges Capacity

D.2.3.1. The Gravity Load Simulator

- Capacity of Gravity Load Simulator:

  Vertical Load (upwards) = 200 kN

  Vertical Load (downwards) = 150 kN

as indicated in Figure D.2.

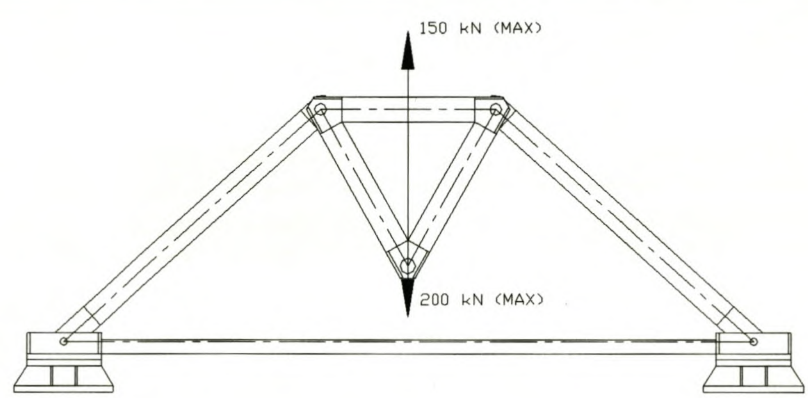


Figure D.2. The Loading Capacity of the Gravity Load Simulator

D.2.3.2. 600 kN Servo Hydraulic Actuator Bridge (and Hinge)

Maximum unfactored static load = 600 kN

The factored end reaction at the hinge should not exceed the load capacity of the track as given in section D2.2 as this will exceed the capacity of the test floor.

D.2.3.3. 62.5 kN Servo Hydraulic Actuator Bridge (and Hinge)

Maximum unfactored static load = 62.5 kN

D.2.4. The End/ Span Supports Capacity

The factored reaction the supports transfer to the Tracks and the Test Floor should not exceed the load capacity of the test floor or track as given in sections D.2.1 and D.2.2 respectively.

D.2.4.1. The Support Bridge

The Loading and Deflection Envelope of a support bridge is given in Figure D.3.

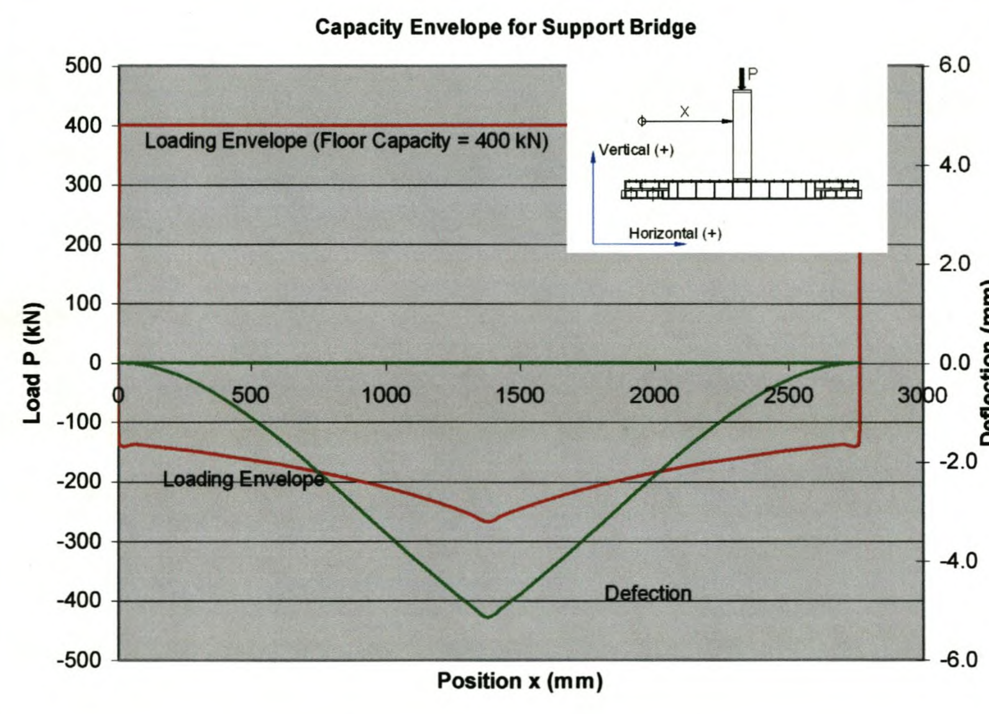


Figure D.3. Capacity Envelope for Support Bridge

D.2.4.2. The Vertical Supports

The loading and deflection envelope of a vertical support is given in Figures D.4 to D.9 for testing at the 1.5 m level, in Figures D.10 to D.15 for testing at the 2.3 m level and in Figures D.16 to D.18 for testing a cantilever beam.

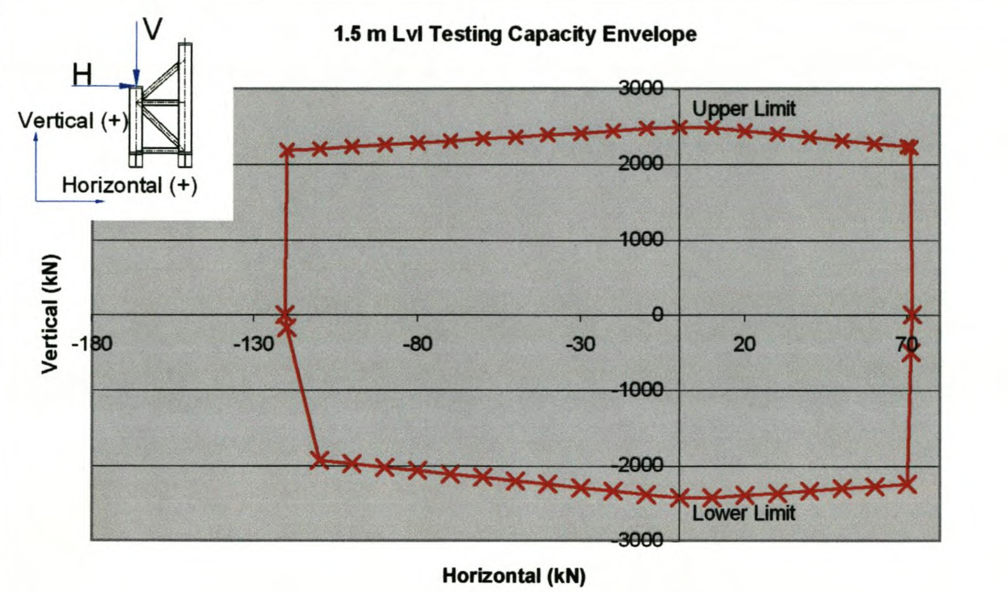


Figure D.4. 1.5 m Lvl Support: Load Capacity Envelope

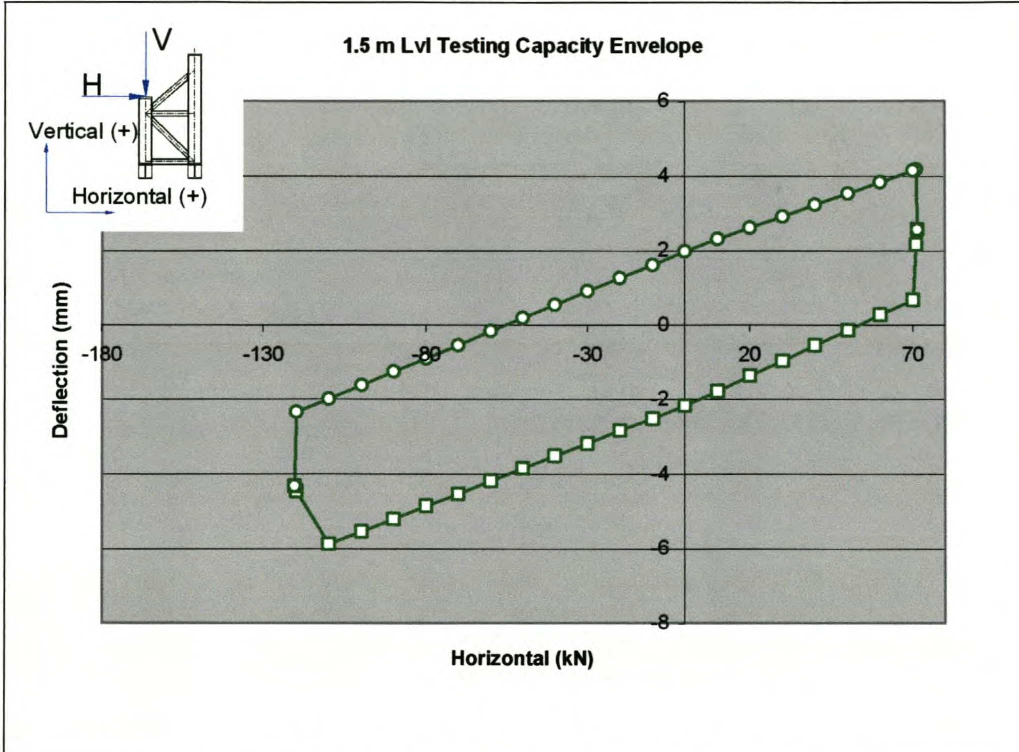


Figure D.5. 1.5 m Lvl Support: Horizontal Deflection Capacity Envelope

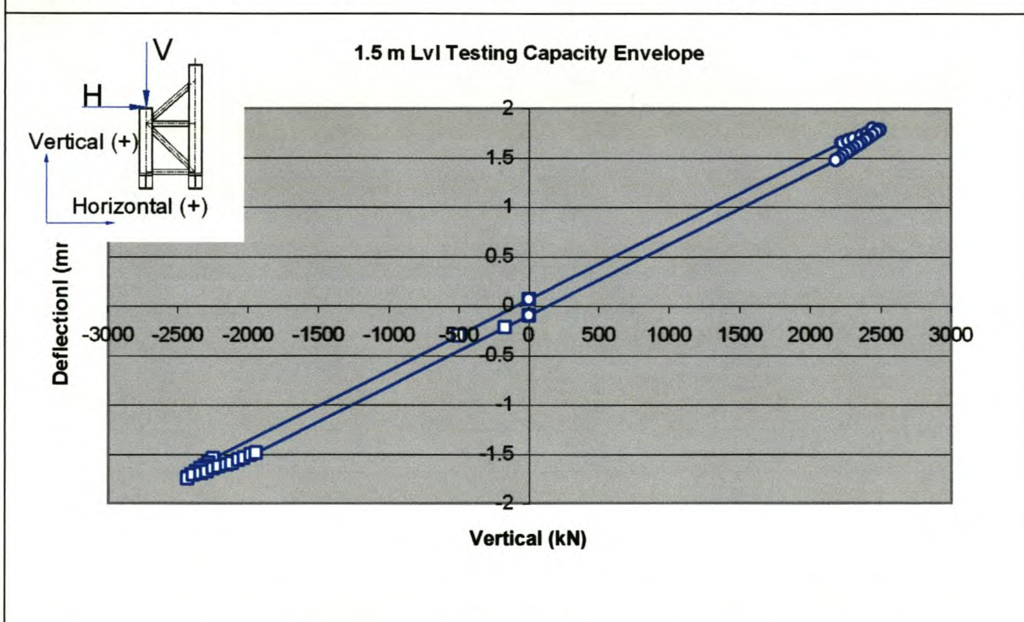


Figure D.6. 1.5 m Lvl Support: Vertical Deflection Capacity Envelope

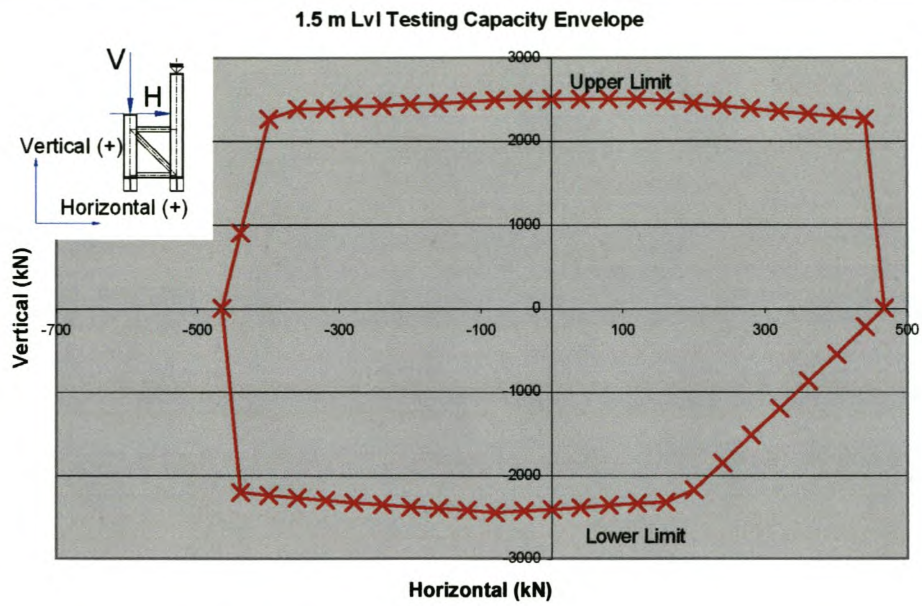


Figure D.7. 1.5 m Lvl Adjusted Support: Load Capacity Envelope

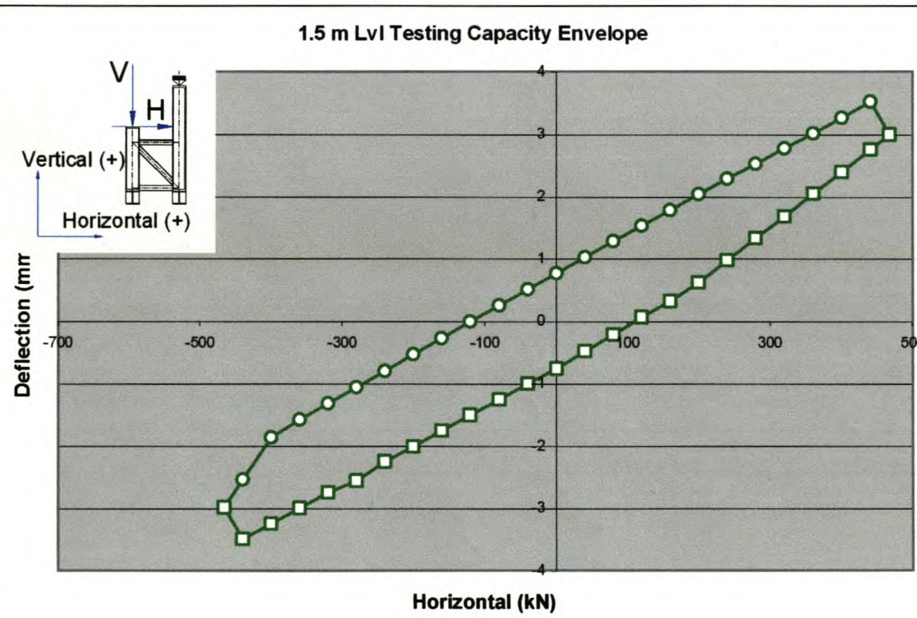


Figure D.8. 1.5 m Lvl Adjusted Support: Horizontal Deflection Capacity Envelope

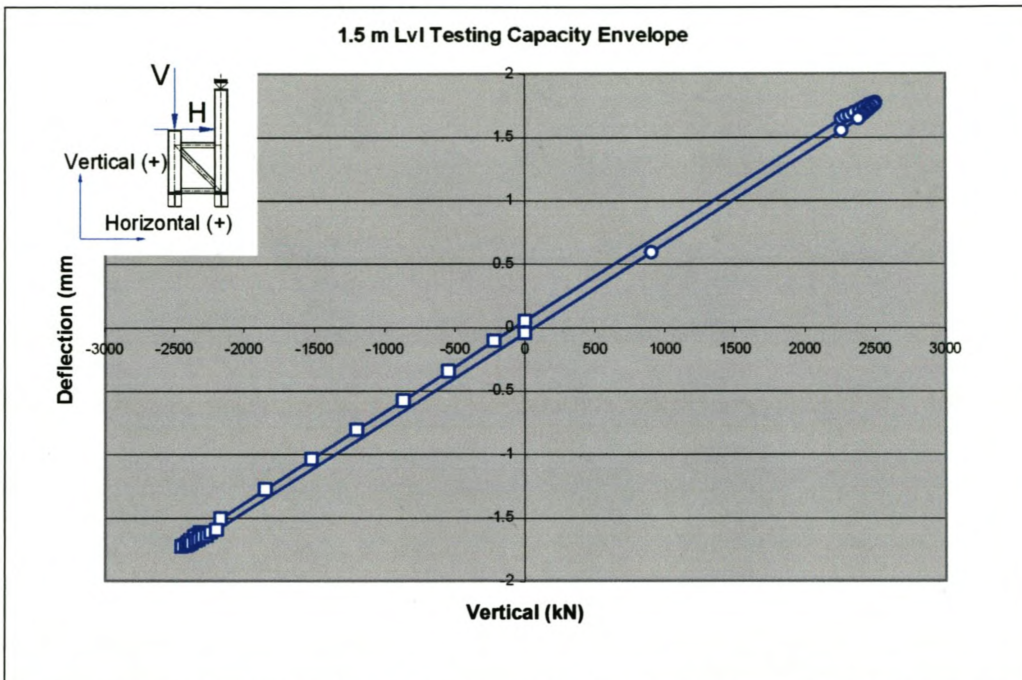


Figure D.9. 1.5 m Lvl Adjusted Support: Vertical Deflection Capacity Envelope

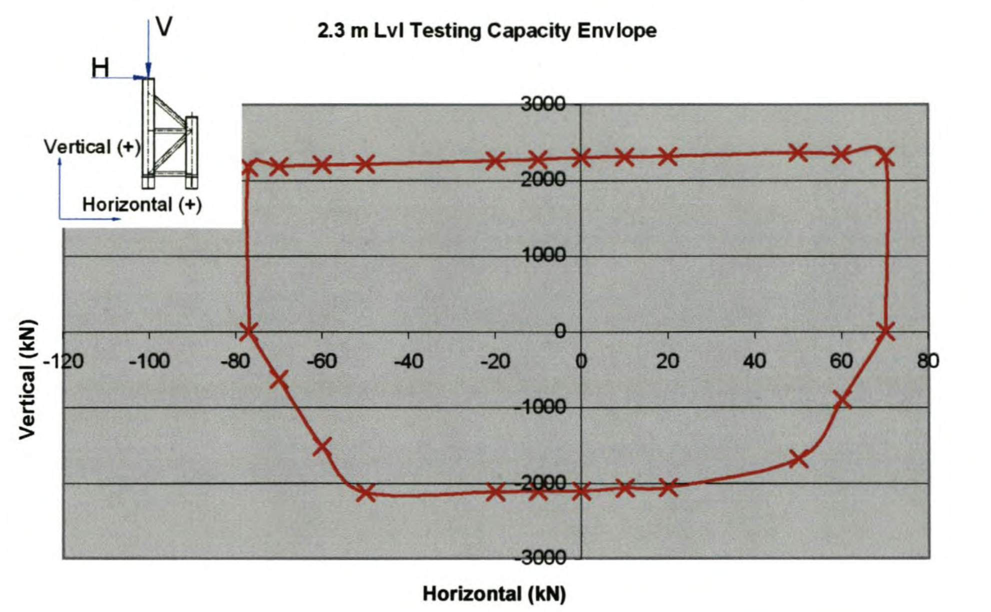


Figure D.10. 2.3 m Lvl Support: Load Capacity Envelope

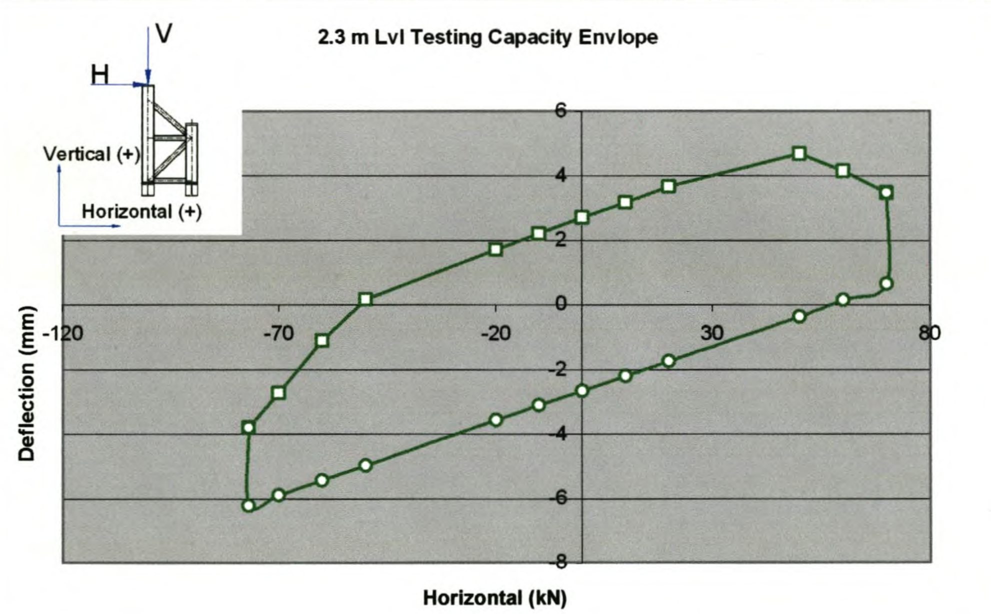


Figure D.11. 2.3 m Lvl Support: Horizontal Deflection Capacity Envelope

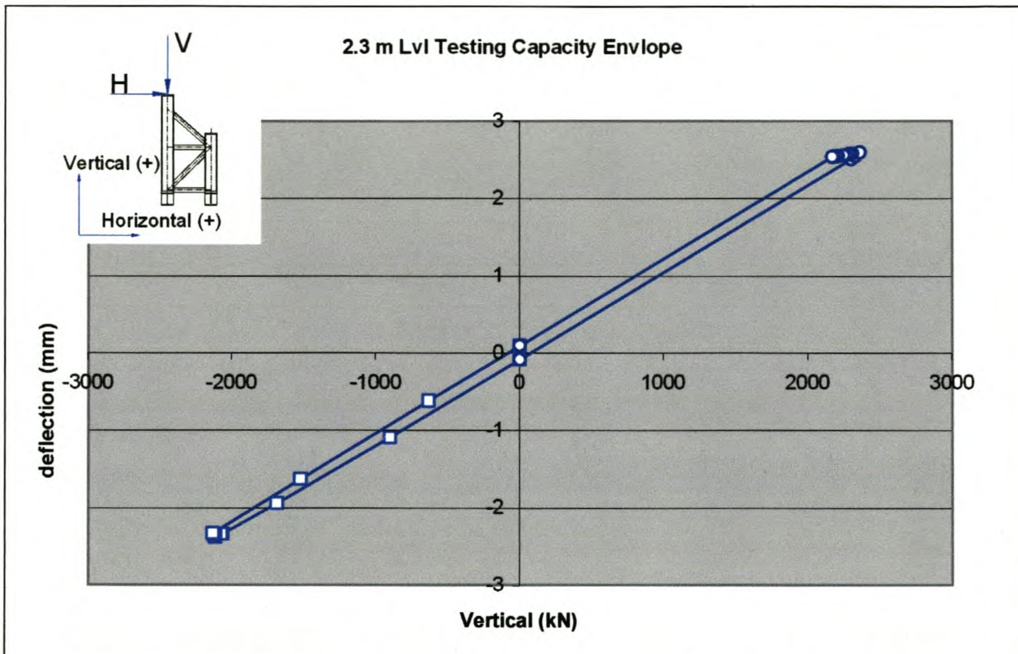


Figure D.12. 2.3 m Lvl Support: Vertical Deflection Capacity Envelope

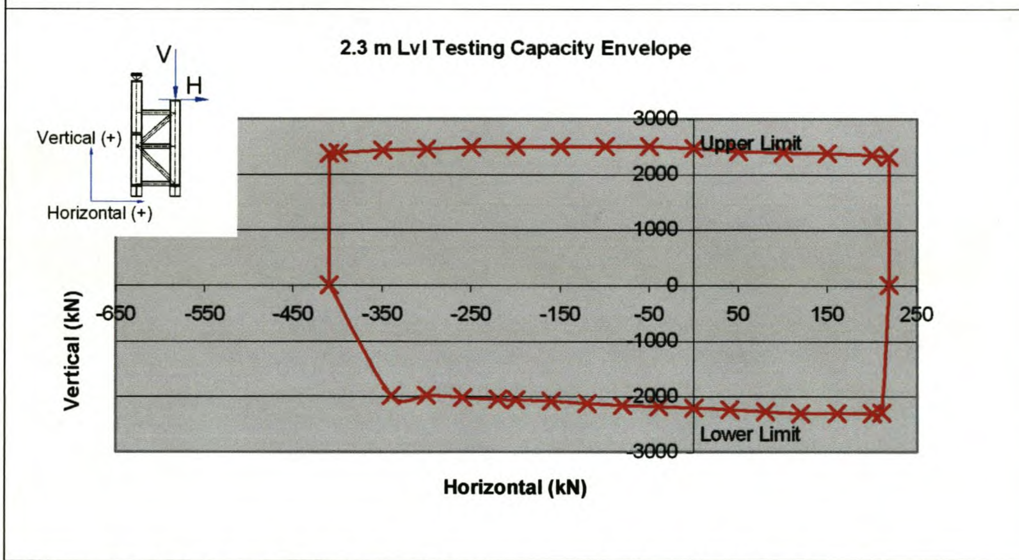


Figure D.13. 2.3 m Lvl Adjusted Support: Load Capacity Envelope

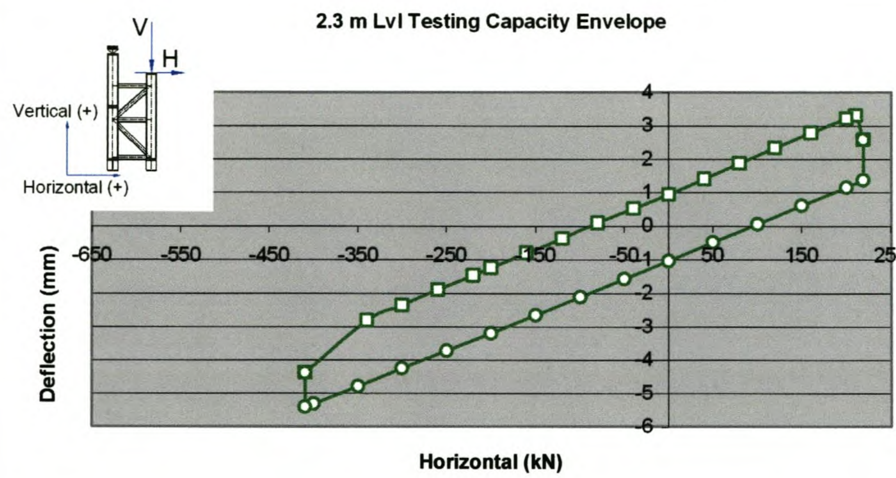


Figure D.14. 2.3 m Lvl Adjusted Support: Horizontal Deflection Capacity Envelope

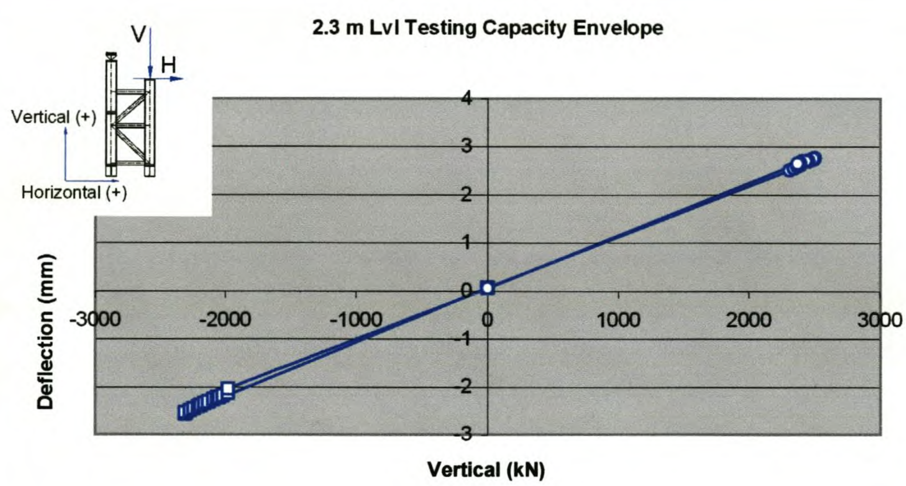


Figure D.15. 2.3 m Lvl Adjusted Support: Vertical Deflection Capacity Envelope

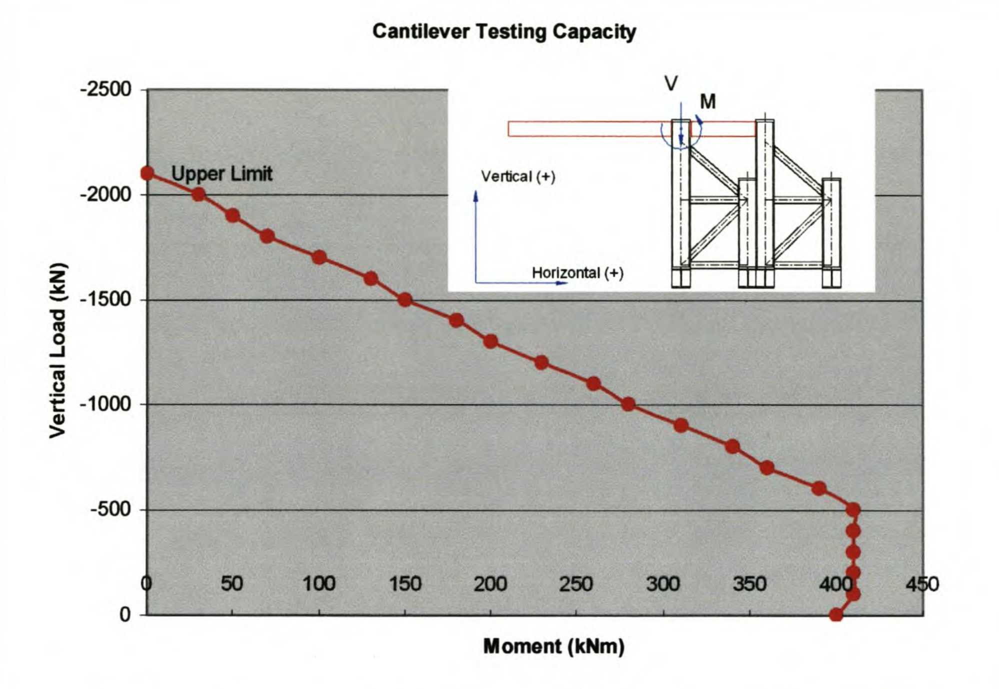


Figure D.16. Cantilever Testing: Load Capacity Envelope

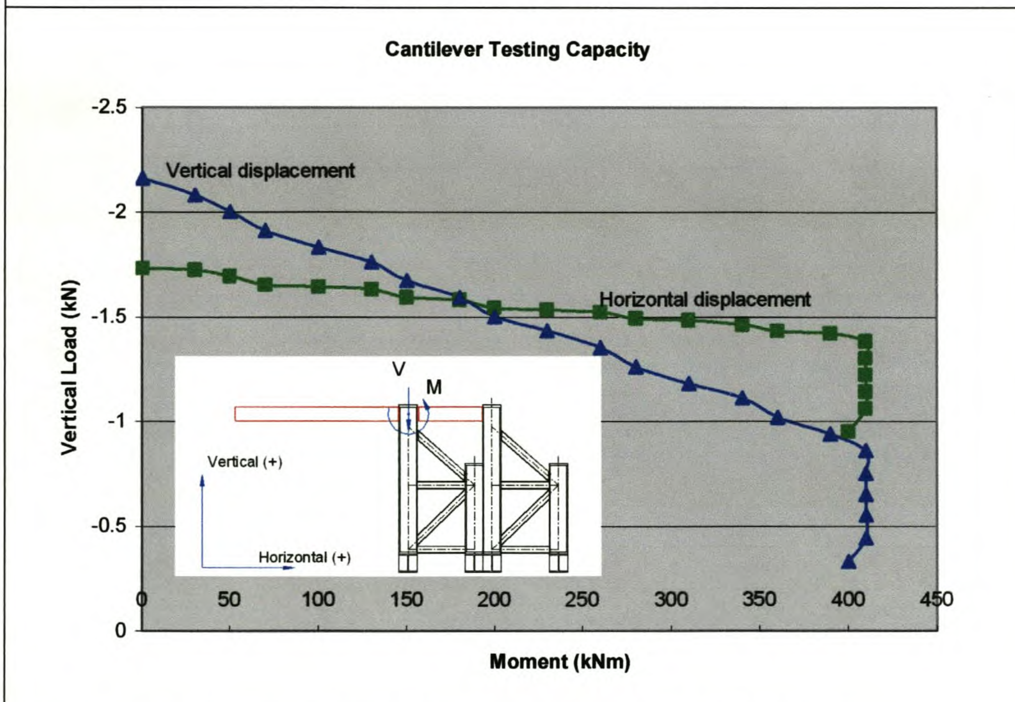


Figure D.17. Cantilever Testing: Displacement Capacity Envelope

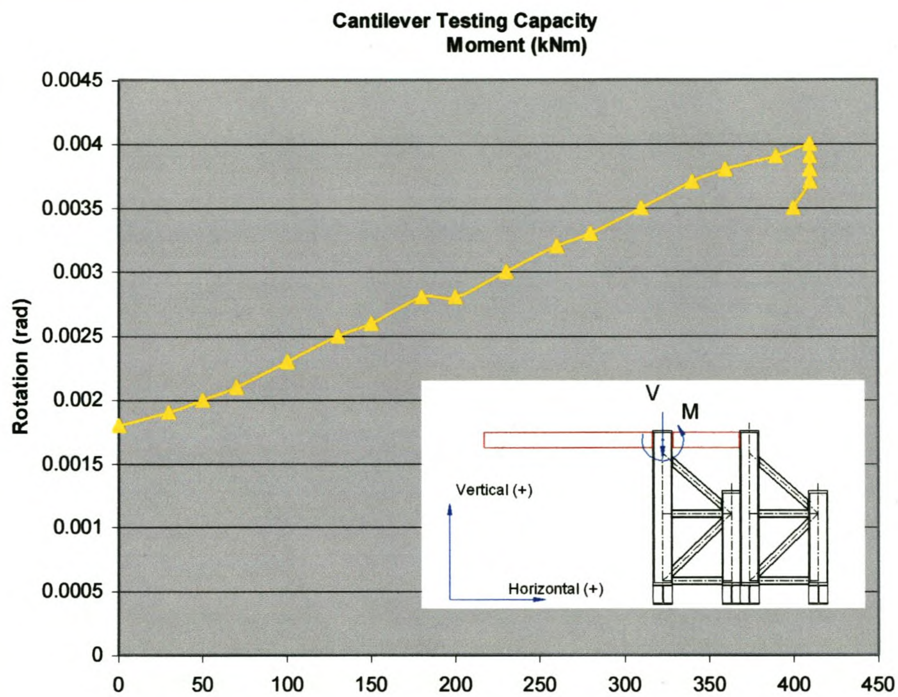


Figure D.18. Cantilever Testing: Rotation Capacity Envelope

D.2.5. Lateral Support Capacity

The load and deflection capacity of the support is given in Figure D.19 and Figure D.20 respectively. The load capacity for the lateral support frame using a tie brace is given in Figure D.21 and the deflection of the support frame for loading at various heights is given in Figure D.22.

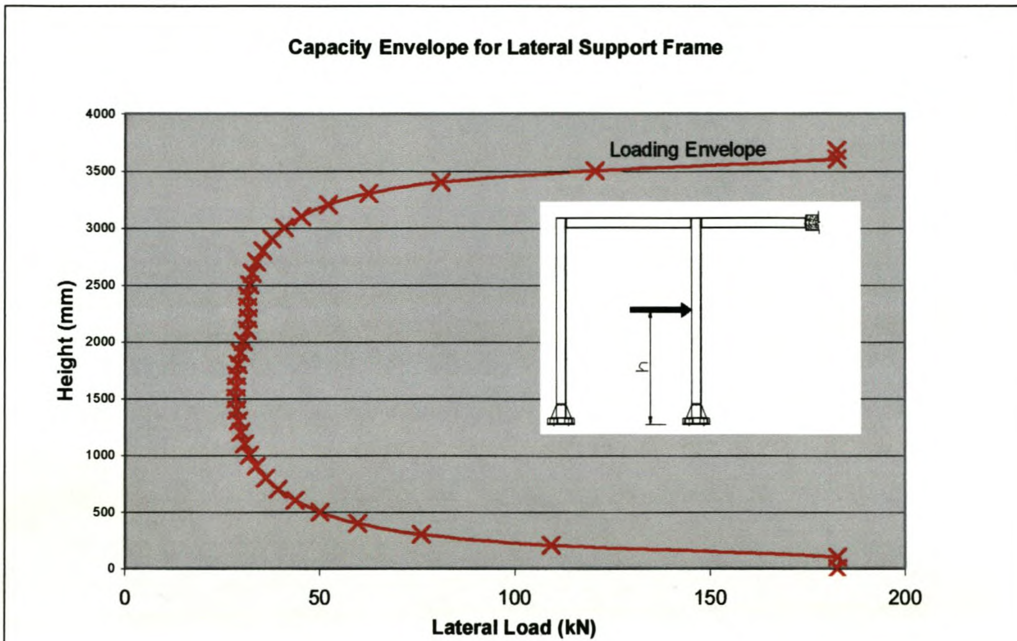


Figure D.19. Lateral Support Frame: Load Capacity Envelope

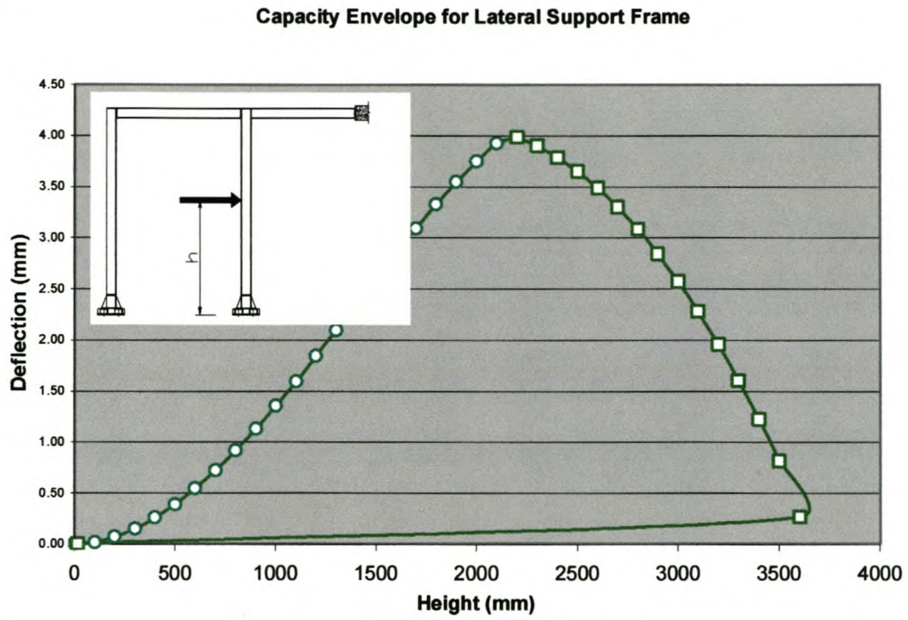


Figure D.20. Lateral Support Frame: Deflection Capacity Envelope

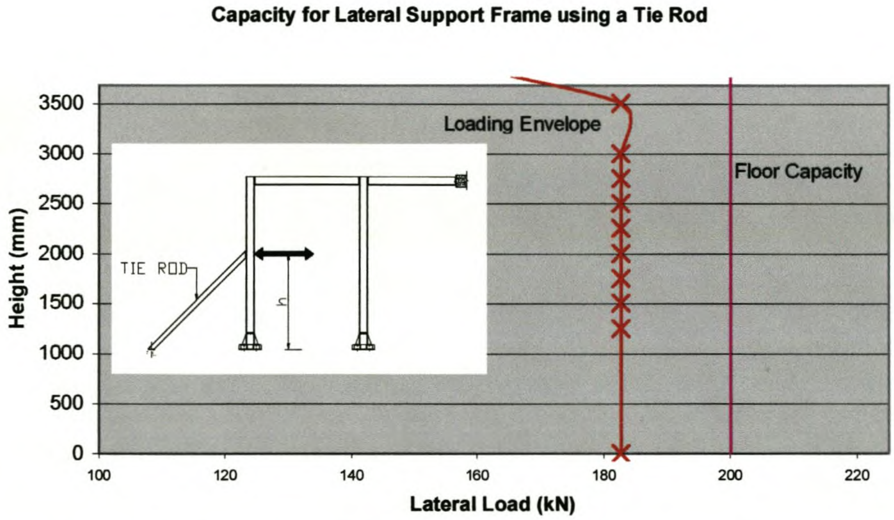


Figure D.21. Capacity of the Lateral Support Frame using a Tie Rod

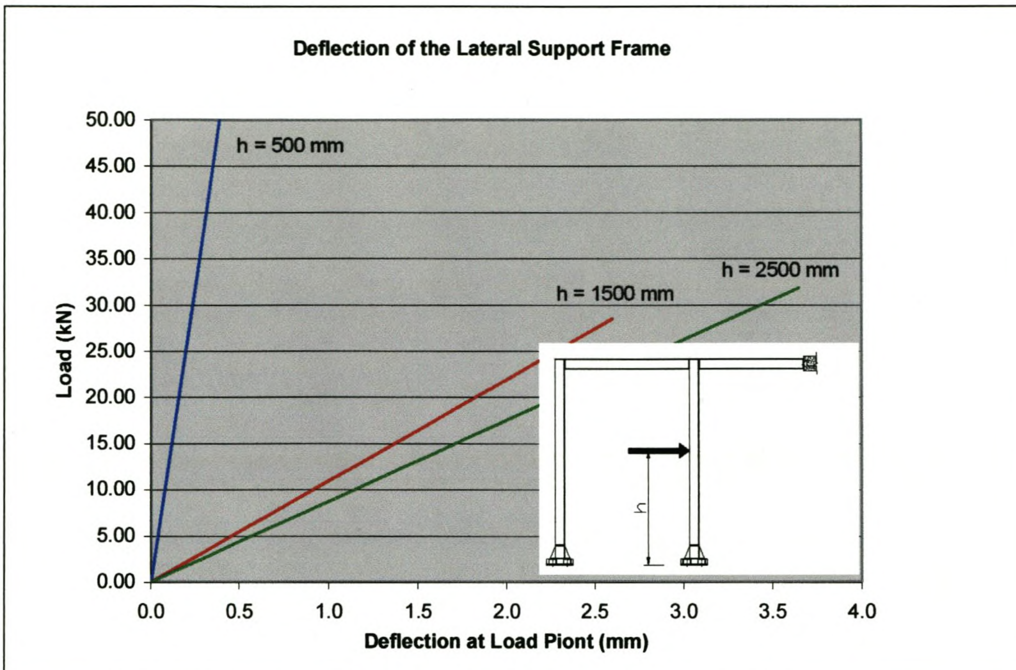


Figure D.22. Deflection of the Lateral Support Frame