EFFECT OF CASES OF LOADING AND BASE-PLATE STIFFNESS ON THE BEHAVIOUR OF THREE-DIMENSIONAL STEEL PALLET RACK SYSEM

By
Feryal H. Al qarud

Supervisor
Dr. Anis S. Shatnawi

Co- Supervisor
Dr. Mutasim S. Abdel-Jaber

This Thesis was Submitted in Partial Fulfillment of the Requirements for the Master's Degree of Science in Civil Engineering

Factuality of Graduate Studies
The University of Jordan

February, 2009

COMMITTEE DECISION

The decision of certified of published / accepted for publication master thesis

This master thesis is accepted for publication under the title:

Influence of Partial Loading on the Behaviour of Pallet Rack Structures

In journal: Advanced Steel Construction, an International Journal

IJASEC08-0049

Date: 20/ September / 2008

Scheduled for Publication on: Vol. 6 No.2, June 2010

Supervisor
Dr. Anis S. Shatnawi

Deputy Dean of the faculty of graduated studies

DEDICATION

To my beloved parents

AKNOWLEDGEMENT

The author wishes to express her appreciation and gratitude to his super adviser Dr. Anis S. Shatnawi and to his co-advisor Dr. Mutasim S. Abdel-Jaber. Special thanks do to Dr. Mutasim S. Abdel-Jaber and Prof. Rob Beale (Department of Mechanical Engineering, Wheatley Campus, Oxford Brookes University) for there efforts in preparing this work.

Finally the author expresses special thanks to her parents for all the years of their sacrifices and encouragement.

Table of Content

Page

List of Tables

List of Figures

EFFECT OF CASES OF LOADING AND BASE-PLATE STIFFNESS ON THE BEHAVIOUR OF THREE-DIMENSIONAL STEEL PALLET RACK SYSEM

By
Feryal H. Al qarud

Supervisor
Dr. Anis S. Shatnawi

Co- Supervisor
Dr. Mutasim S. Abdel-Jaber

ABSTRACT

Steel storage pallet racks are used for storing industrial goods. In practical situations such goods may be removed from some parts of pallet racks. This Study presents the results of an investigation into the effects of partial loading on the behaviour of steel pallet racks. A six level, six bay, 3-dimensional pallet rack frame model was built using ABAQUS and a geometrically non-linear analysis conducted. Twelve different load combinations were analysed under different boundary conditions and different side imperfections. Most combinations failed by sway buckling. Depending upon the side imperfection and the base condition critical combinations involved having completely unloaded bays or lifts adjacent to two or more fully loaded bays or lifts with reductions in capacity over a fully loaded rack of up to 40%.

Chapter One

INTRODUCTION

1.1 Background and Research Significance

Steel storage pallet racks are widely used throughout the world for storing industrial goods. Moreover these structures provide high storage density. The goods to be stored are generally in cartons or boxes stored on pallets. A typical example is shown in Figure 1.

Pallet racks are commonly made from cold roll formed steel. Such structures usually have a large number of bays and beam levels. The main components for racking system are vertical supports or uprights, beams, connections and bracing. Uprights are generally thin-walled, perforated open sections with low torsional stiffness. The beams are often thin-walled closed sections with high torsional stiffness. Bracing systems are generally placed in the cross aisle direction. The connections between beams and uprights are semi-rigid and are usually made by the use of tabs and lugs welded onto the ends of beams making a boltless into the perforations of the uprights. [1]. Bolted connections are used to connect the upright with the ground. The base-plate connections can be considered either as semi-rigid or pinned although research by Beale and Godley [2] has shown that under certain combinations of side loads that pinned connections can carry higher loads. Godley [3] has also pointed out that under many load combinations that the difference in performance between semi-rigid and rigid bases can often be considered negligible and that in many cases bases can be considered as either pinned or fixed.

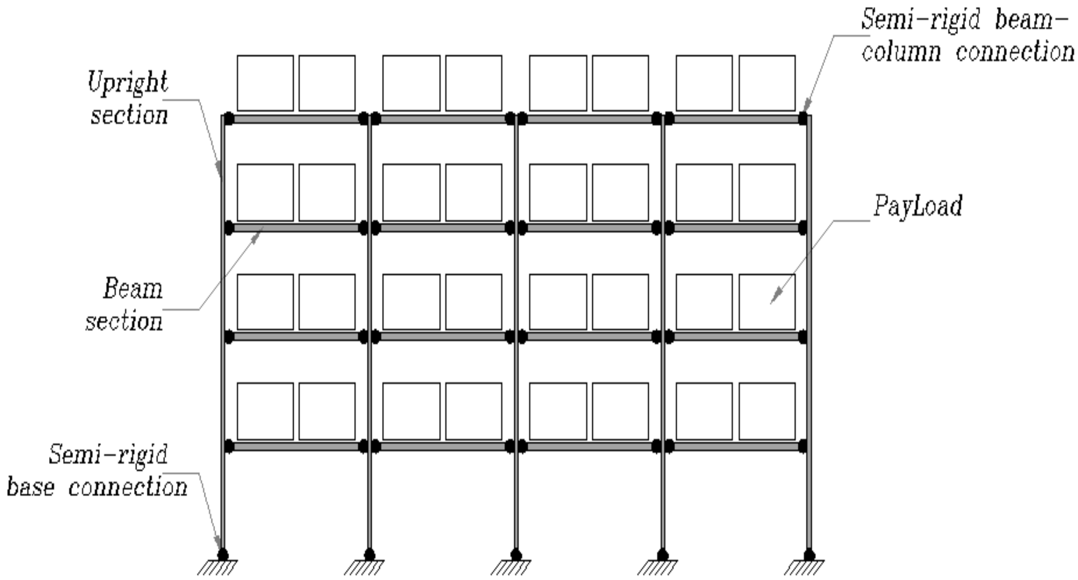


Figure 1. Pallet Rack Structure

1.2 Previous studies

A numerous amount of research papers were reported on the subject of analysis and design of steel storage pallet rack structures. Moreover, beside the theoretical investigation some of these studies concentrated on the experimental analysis of pallet rack especially in sway and connection (*i.e.;* semi-rigid connecters) analysis.

These studies (Godly et al., 1997) [1] focused on the beam end connector which is subjected to a combined axial load and bending moment and present the result of the tests carried out on a selected number of connectors and compares their moment-rotation characteristic. Moreover a theoretical investigation is carried out to estimate the influence of the flexibility of the beam used in the tests on the stiffness determine experimentally. Finally they listed the main factors effecting efficient beam end connector design as the number of tabs; increasing the number of tabs will lead to increases in the stiffness and strength of the beam end connector, the design of the brackets and the geometry of the tabs and the profile of the uprights; changing the profile of the upright to increase its stiffness increases the stiffness of the beam end connector. (Godley et al., 2000) [4] developed a model of a single free sway column to analyse an design a typical pallet rack structure subjected to horizontal load and uniform load acting on the beam, and to solve the differential equations of flexure by including (P- Δ) effect. In addition the results of the analysis are compared with non-linear finite element solution of the same problem, and the numerical results shown a good agreement with the finite element analysis. Moreover to study the effects of semi-rigid base-plates on the design of pallet racks the authors introduced analytical model for pallet rack structure that considered the effects of the strength of a base-plate on the design of pallet racks [2]. The study has shown that certain combinations of axial forces and moments on a base-plate can lead to premature failure of the connection. When the base-plate has failed, the pallet rack can be analyzed as a rack on a pinned base to give satisfactory reduced performance. Moreover as the base-plate may fail at low vertical load, the frame can act as a pinned frame until sufficient vertical load is added to make the base-plate act satisfactory as semi-rigid connection. In addition (Godley et al., 2006) [5] introduced a 3-dimensional pallet rack frame model (*i.e.;* 5-lifts highs and 5-bays) built using the LUSAS finite element software. To study the collapse behavior of the structure due to structural damage, they were taken out individual bottom legs one at a time and the buckling and maximum loads determined.

They found that applied out-of-plane side loads affect pallet rack behavior. Moreover, it affects the buckling load factor and thus the maximum load carrying capacity of the frame. The collapse analysis found that the removal of the second rear leg created the most critical condition on the frame.

This study investigates the effects on the total load carrying capacity of the frame of different types of pattern loading in combination with different geometrical imperfections. In addition, this study compares frame response under different base conditions - semi-rigid, pinned and fixed.

1.2 Objectives of Research:

The main purpose of this study is to investigate the effect of partial loading on the behavior of a pallet rack. The focus will be on investigating the response of the frame under cases of loading with different type of base fixation (Rigid, Semi-rigid and Pinned):

1. To built up a non-linear, three-dimensional model of a typical pallet rack, 6-lifts highs, and 6-bays width.
2. To place a uniformly distributed load on all horizontal members (*i.e.;* beams) and determine the load carrying capacity of the frame.
3. to find appropriate connector element at these connection point:
    - Between uprights and beams and between uprights and base-plate (semi-rigid connection)
    - Between uprights and bracing members (pinned connections)

    Moreover molding these types of connections required using a special type of connectors that represents the required kinematics constraints.
4. To study the effect of cases of loading through the following:
    - Appling UDL to all horizontal members.
    - Removing the loading on alternate bays for all lifts.
    - Applying checker-boar loading by removing loads on alternate bays and columns.
    - Loading two bays in three.
    - Removing the loading on alternate levels.

- Removing the loading on one bay in the bottom two levels.
- Appling an initial out-of-plumb due to frame imperfections, in down aisle and cross aisle directions.

5. To carry out a comparative study of the frame response between rigid, semi-rigid and pinned base under above cases of loading.
6. To investigate the effect of the above cases of loading on the response of the base-plate.
7. To investigate the effect of the base-plate stiffness on the capacity of the pallet rack.

1.4 Research Methodology

The effect of cases of loading on the behavior of a pallet rack steel framed structure will be investigated.

In order to deal with such models, a highly sophisticated finite element program that can include the nonlinearity effects. ABAQUS is a good example of such programs.

In particular, the research methodology includes the following:

1. A representative multi-story pallet rack frame, and base-plate, will be modeled regarding the following considerations:
    - The model will be created using a nonlinear finite element package as ABAQUS.
    - Assumptions when modeling the materials:
        - Elastic member behavior
        - The simulation will include nonlinear geometric effects.
    - A suitable connector element include:
        - Semi-rigid connections between uprights and beams and between uprights and base-plate depending on the exact moment-rotation curve of each point.
        - Pinned connections between uprights and bracing member.

2. Perform a static riks analysis:
    - Applying an initial out-of-plumb angle due to frame imperfections, in down and cross aisle direction.

- Applying uniformly distributed load on the horizontal members with cases of loading as:
  - Appling UDL to all horizontal members.
  - Removing the loading on alternate bays for all lifts.
  - Applying checker-boar loading by removing loads on alternate bays and columns.
  - Loading two bays in three.
  - Removing the loading on alternate levels.
  - Removing the loading on one bay in the bottom two levels.
  - Appling an initial out-of-plumb due to frame imperfections, in down aisle and cross aisle directions.
- Compute the maximum load that the structure can carry.

Chapter Two

LITERATURE SURVEY

2.1 Analysis of Beam Pallet Racks

Steel storage pallet racks can be classified into two types with reference to their bracing system to:

2.1.1 Un-braced pallet rack systems

Figure 1.1 shows a typical un-braced pallet rack, in which the down-aisle stability is provided solely by the restraining effect of the beam end connectors. In cross-aisle direction, stability is provided by the bracing in the frames which, in the case of double entry rack shall be linked together in the height by run spacers.

2.1.2 Braced pallet rack systems

In a braced pallet rack, forces acting in the front plane shall be transferred to the spine bracing in the rear plane through the upright frames adjacent to the braced bays. For the braced pallet racks shown in Figure 1.2, down-aisle stability is provided by spine bracing in the vertical plane at the rear of the rack. The stabilising effect of the spine bracing is transmitted to the un-braced uprights at the front of the rack by means of plan bracing. Cross–aisle stability is provided by means of braced frames.

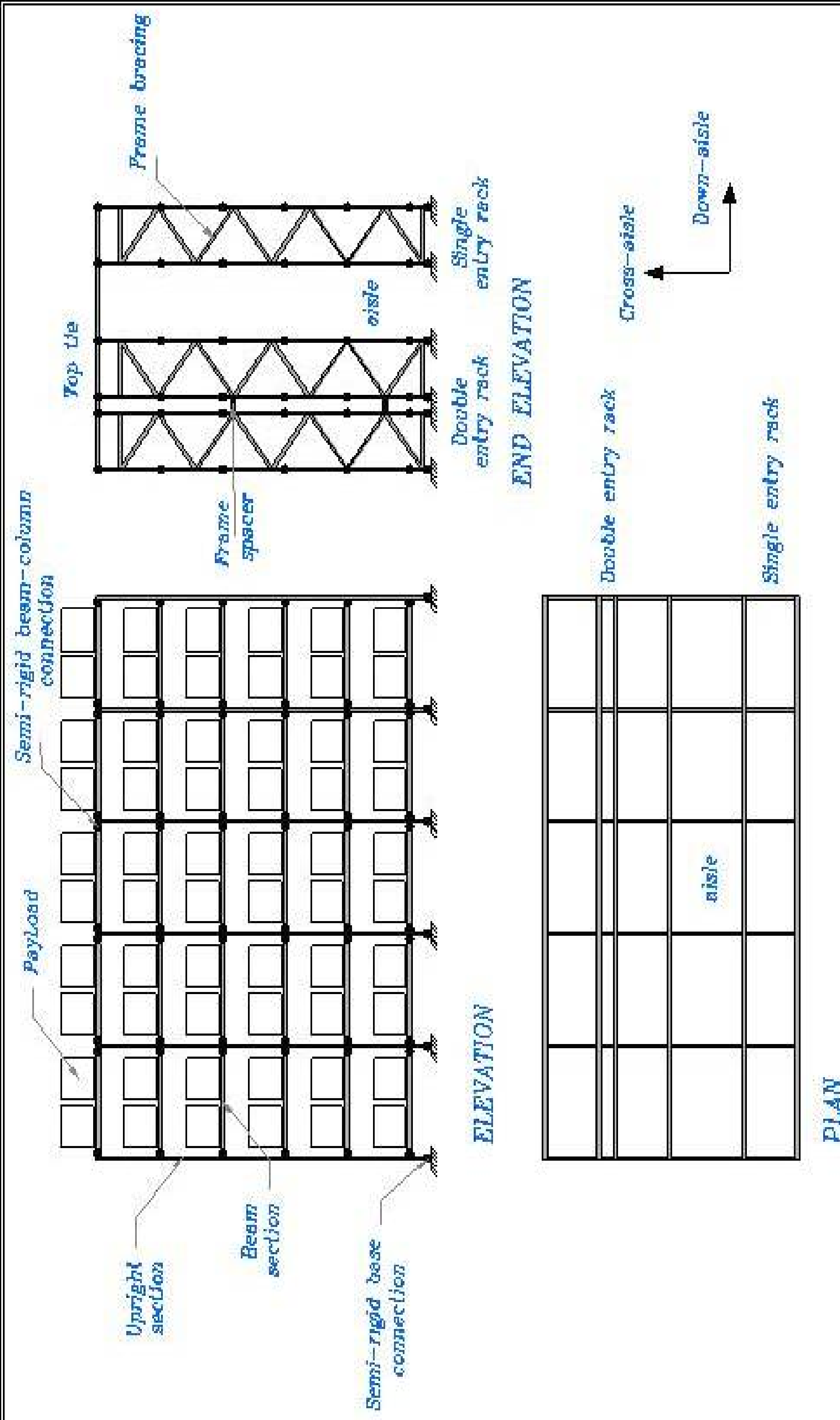


Figure 1.1 Typical unbraced pallet rack structure.

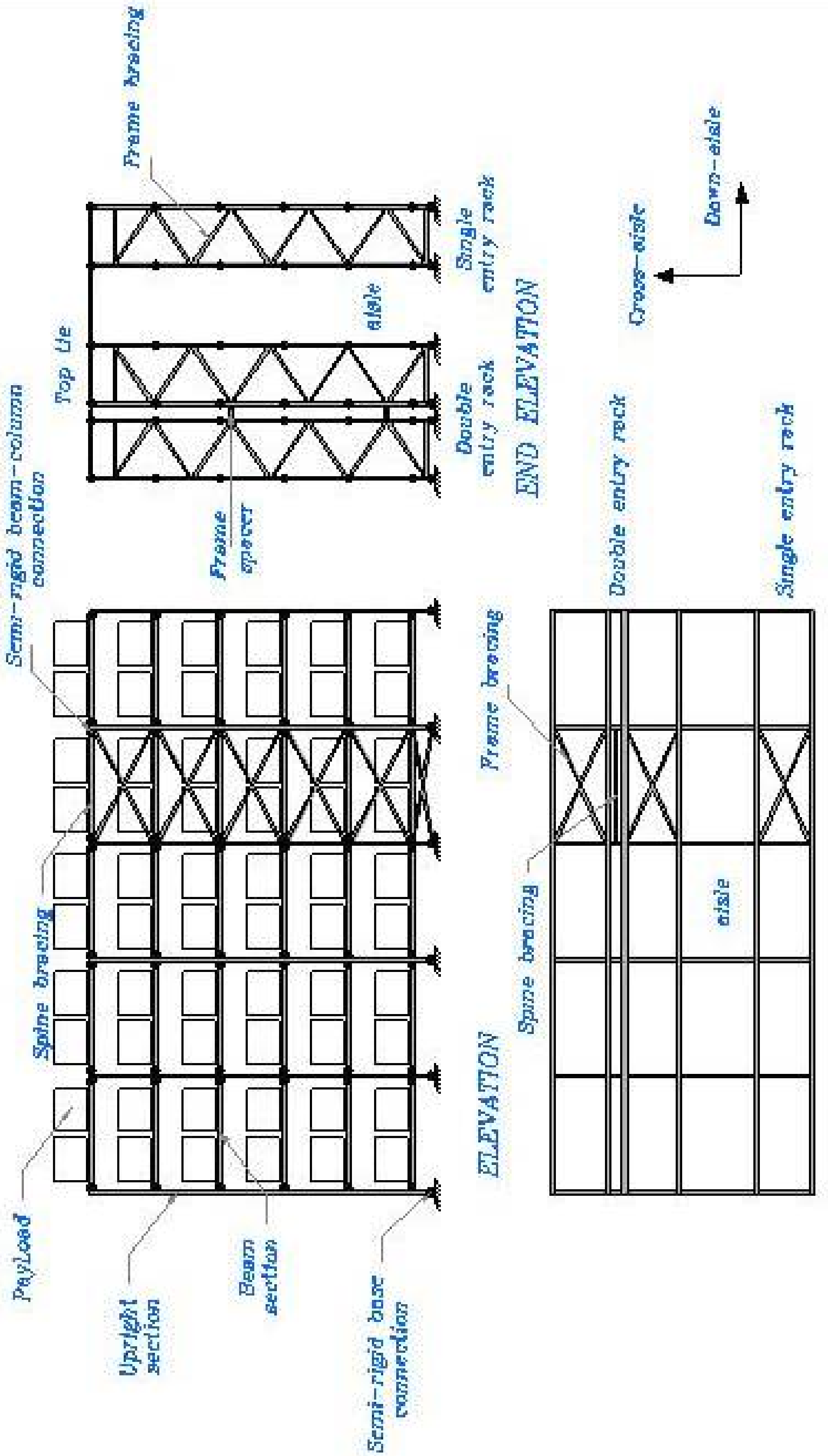


Figure 1.2 Typical braced pallet rack structure.

In order to study the effect of partial loading on the behaviour of the model adopted in this study a suitable analysis according to Federation Europeene de la Manutention (FEM) code for storage system is chosen.

2.2 Methods of analysis

A comprehensive analysis of a complete frame in either down-aisle or cross-aisle direction may be carried out in one of two ways:

1. Using second-order elastic or elastic-plastic analysis, in which the structural components are represented by prismatic members and the connections have appropriate moment-rotation characteristic.

There are two ways to model beam end connectors:

- The beam-upright connectors may be modeled as rotational springs of constant stiffness.
- The beam-upright connectors may be modeled as a non-linear rotational springs.

2. Using first-order elastic analysis, in which the structural components are represented by prismatic members and the connections by springs and in which the second-order effect are treated indirectly.

2.3 Design procedure

The analysis of a rack system may be undertaken by considering the down-aisle and then cross-aisle direction:

2.3.1 Analysis of un-braced racks in the down-aisle direction:

The stability in the down-aisle direction requires a rational analysis which takes account of the following factors:

- The destabilizing effect of axial compressive loads in the uprights (Second-order effects).
- The moment rotation characteristics of the beam to upright connections.
- The moment-rotation characteristics of the upright to floor connections.
- The moment rotation characteristics of splices in the upright.
- Actions arising from down-aisle imperfections.

2.3.2 Analysis of un-braced racks in the cross-aisle direction:

The stability in the cross-aisle direction requires a rational analysis which takes account of the following factors:

- The shear flexibility of the bracing system including the effect of flexibility of the connections between the uprights and the bracing member.
- The moment rotation characteristics of splices in the upright.
- Loads originating from handling equipment.
- The moment-rotation characteristics of the upright to floor connections.
- The overall stability of the braced frame.
- Actions arising from down-aisle imperfections in the cross-aisle.

2.4 Load combinations for analysis

2.4.1 load combinations for analysis in the down-aisle direction:

In the down-aisle direction the structure should be analysed for the following loads in combination:

- Dead load.
- Imposed load from stored materials.
- Imposed load from walkways or floors.
- Actions arising from imperfections in the down-aisle direction.
- Imposed load from handling equipment.

In considering imposed loads from stored materials, the worst loading pattern should be considered for each of the following criteria:

- Overall stability in the down-aisle direction.
- Bending and buckling of the upright.
- Beam deflections and mid-span bending moments.
- Moments in the beam to upright connectors.

For the overall stability in the down-aisle direction, it is sufficient to consider the fully loaded structure with the actions arising from imperfections.

For the design of the uprights it is required that both fully loaded condition and the pattern loaded condition shall be considered and this is the main objective of this study.

2.4.2 load combinations for analysis in the cross-aisle direction:

In the cross-aisle direction the structure should be analysed for the following loads in combination:

- Dead load.
- Imposed load from stored materials.
- Imposed load from walkways or floors.
- Imposed load from handling equipment.
- Actions arising from imperfections in the cross-aisle direction.

There is no need to consider pattern loading for these combinations.

2.5 Previous researches

A lot of research has been reported on the subject of analyses and design of pallet rack structures, for example [4-9]. However few of these publications have reported the results of pattern loading as is often required by design codes such as Federation Europeene de la Manutention (FEM) code [10] and the Rack Manufacturers Institute (RMI) code [11].

Beale and Godley [12-13] developed a program to analyse and design regular pallet racks according to the FEM code. The program determines the buckling load of an equivalent free sway structure and using stability functions, calculates the axial and shear forces and the bending moments within the structure including the non-linear ($P - \Delta$) effects. The results of the program showed that pattern load effects in combination with imperfections often dominated the failure loads of the analysed racks.

Morz et al [14] and Olsson and Sandberg [15] presented a numerical study with the aim of investigating the influence of removing components from pallet racks, such as horizontal beams or cross-aisle bracing members. Typical cases considered were removing all five pairs of beams at the lowest beam level or having two pairs of beam missing. The results showed that for all these cases of loading the total load-carrying capacity of frame was reduced and the pallet rack failed in a global down-aisle sway mode.

This study investigates the effects on the total load carrying capacity of the frame of different types of pattern loading in combination with different geometrical imperfections. In addition, this study compares frame response under different base conditions - semi-rigid, pinned and fixed.

Chapter Three

DESCRIPTION OF THE STRUCTURES AND MODELING

3.1 Pallet model

Steel pallet rack structures are 3-dimensional frame systems. The performance of these structures with fixed-bases under 36-load combinations is compared with similar frames with pinned and semi-rigid bases. In the analyses conducted the vertical loads were increased proportionally to determine the maximum loads before failure and the maximum reactions and deflections recorded The model pallet rack considered in this paper contained 6-levels and 6-bays, the height to first story was 400 mm as it is common for racking frames to have a low first story, the height of each subsequent story was 1400 mm and the beam lengths were 2400 mm. Front and rear frames were connected by zig-zag bracing, with an initial horizontal member 100 mm above the ground and with each 'zig' of height850 mm. A horizontal cross–aisle member was at top of the highest 'zig'. The model is shown in Figure 2.

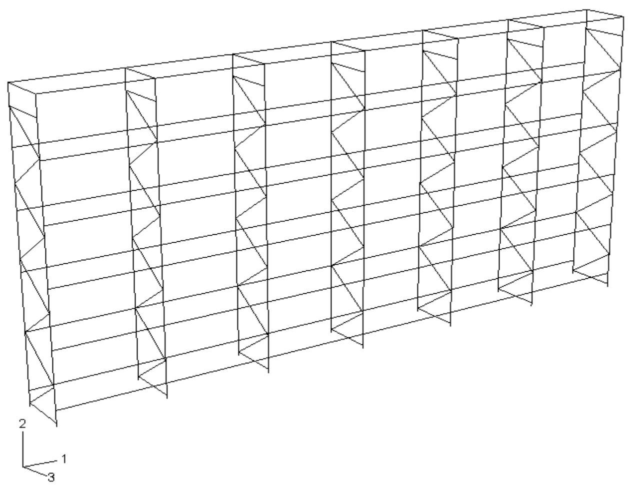


Figure 2. Isometric view of model

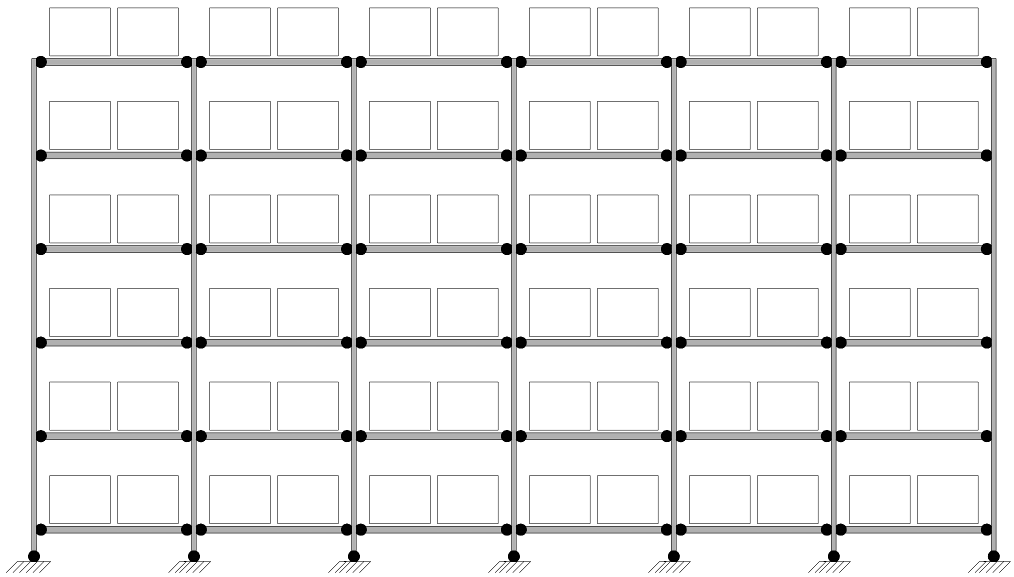
3.2 Cases of loading

36-companations of loads were analysed and the maximum load that the structure carried determined, the choice of these types of loading was due to the eccentricities caused by imperfections. The cases of loading were considered in this paper are:

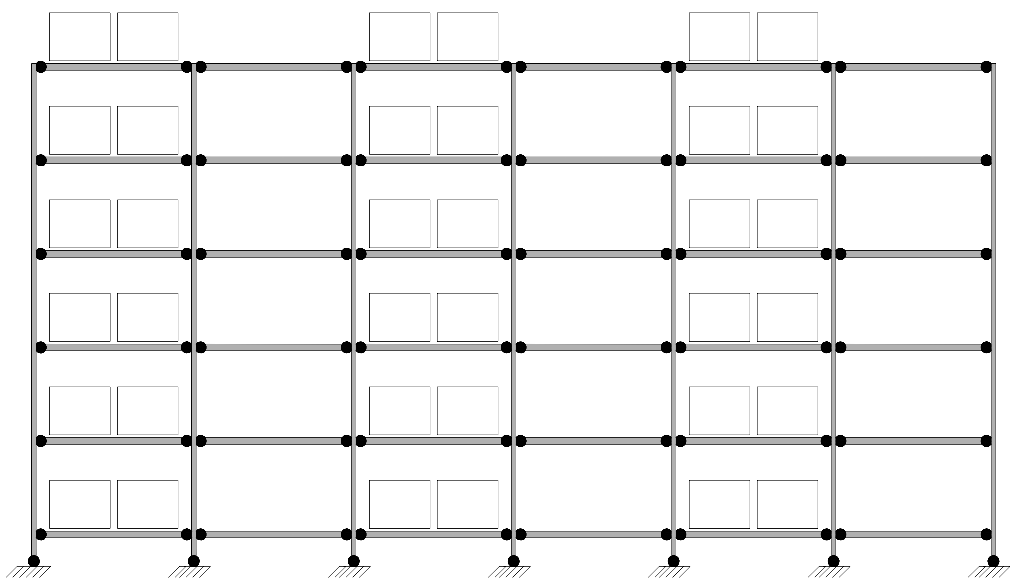
- Appling UDL to all horizontal members (general case).
- Removing the loading on alternate bays for all lifts (case nos.1 and 2)
- Applying checker-board loading by removing loads on alternate bays and columns (case nos. 3 and 4).
- Loading two bays in three (case nos.5 and 6).

- Removing the loading on alternate levels (case nos.7 and 8)
- Removing the loading on one bay in the bottom two levels (case nos.9-12)
- Appling an initial out-of-plumb due to frame imperfections, in down aisle and cross aisle directions.

Figure 3 shows all cases of loading used in the analysis:

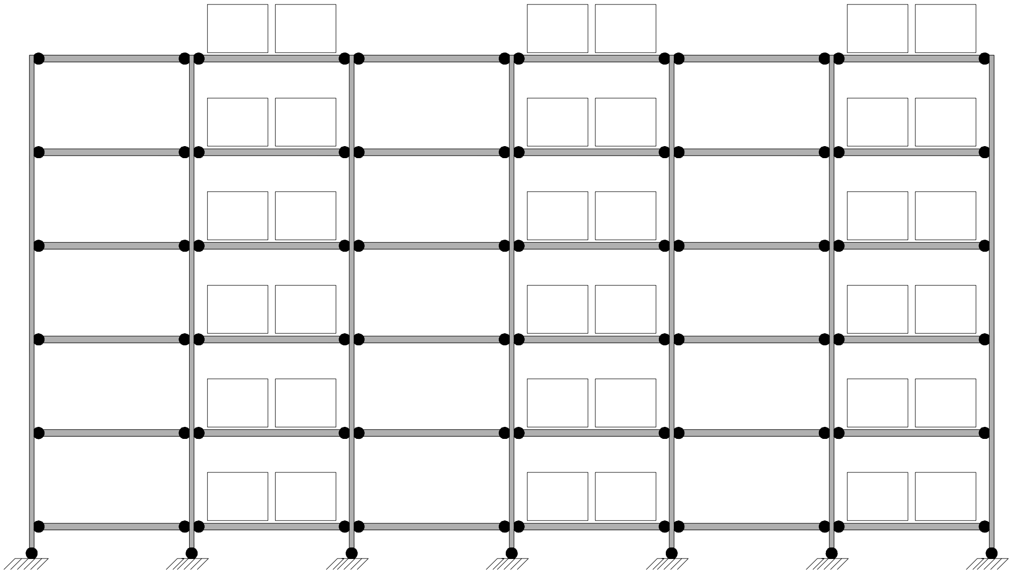


(a) general case

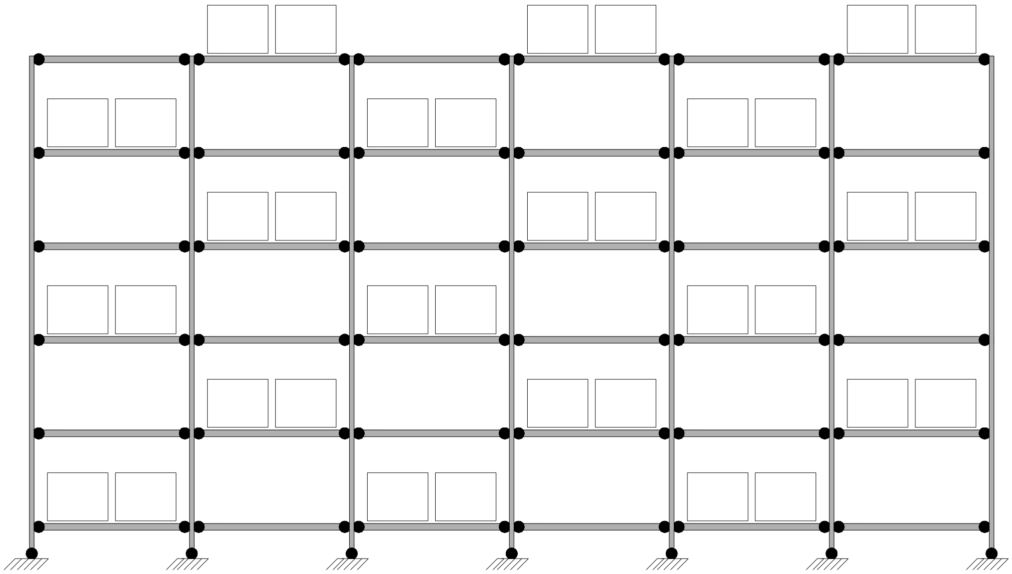


(b) case 1

Figure 3. Cases of loading

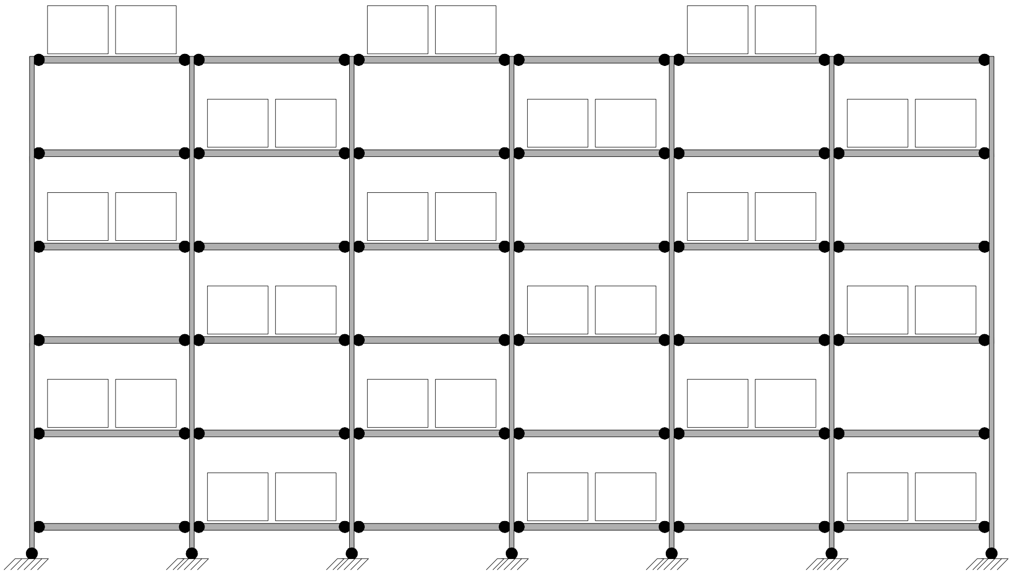


(c) case 2

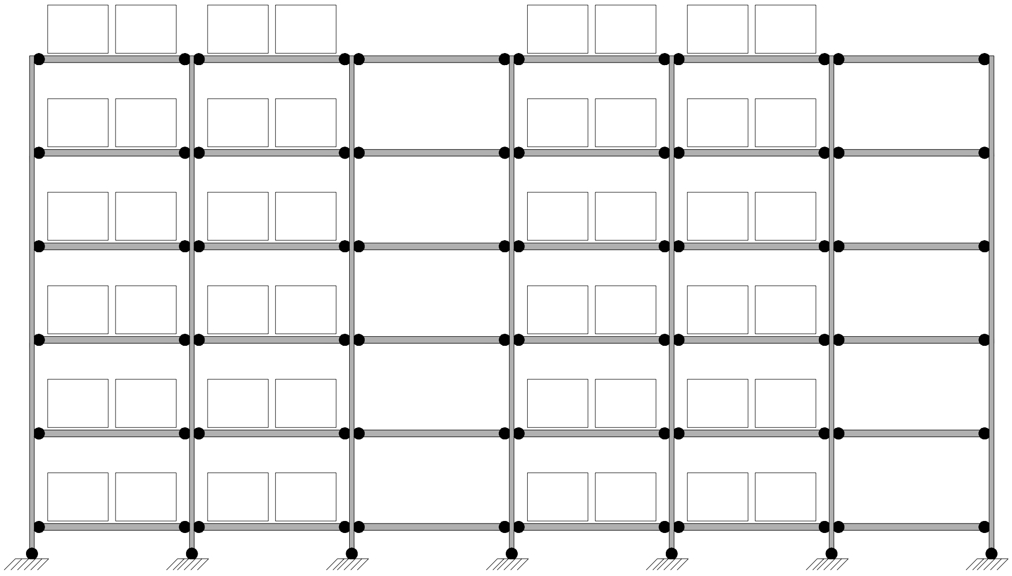


(d) case 3

Figure 3 (continued). Cases of loading

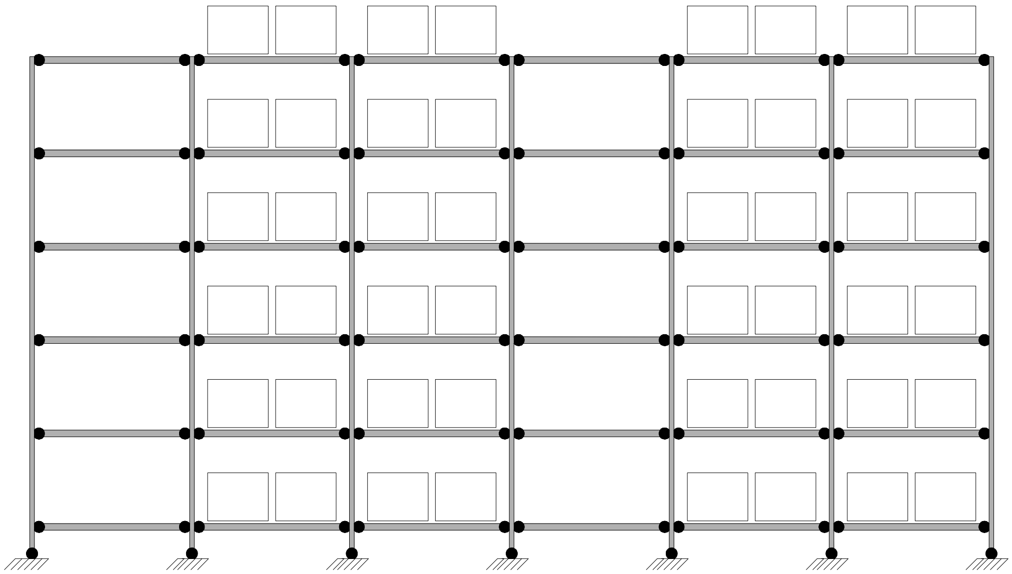


(e) case 4

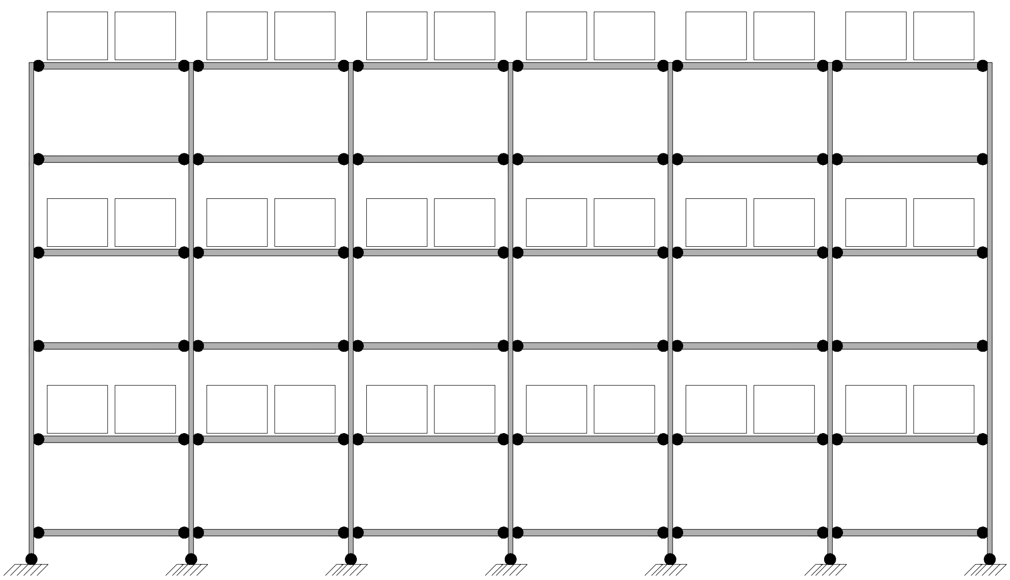


(f) case 5

Figure 3 (continued). Cases of loading

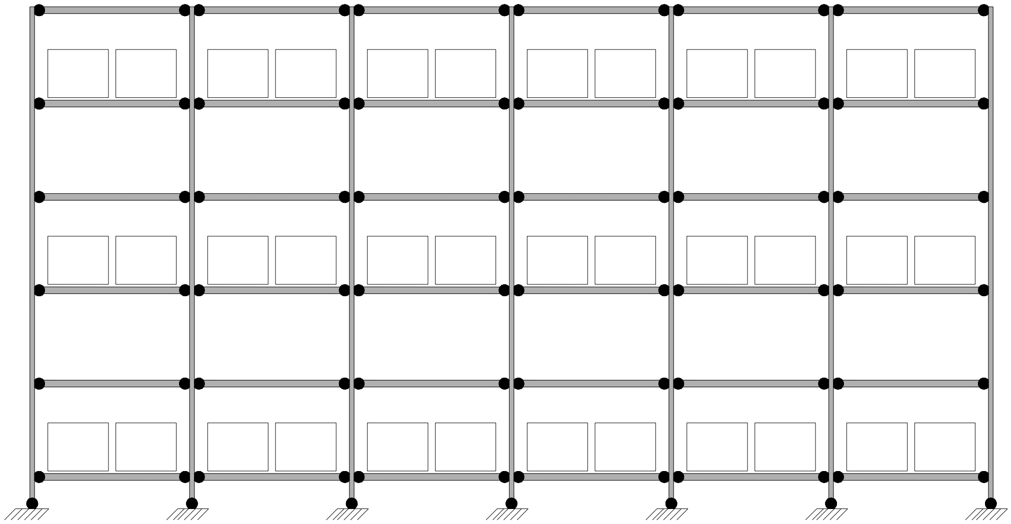


(g) case 6

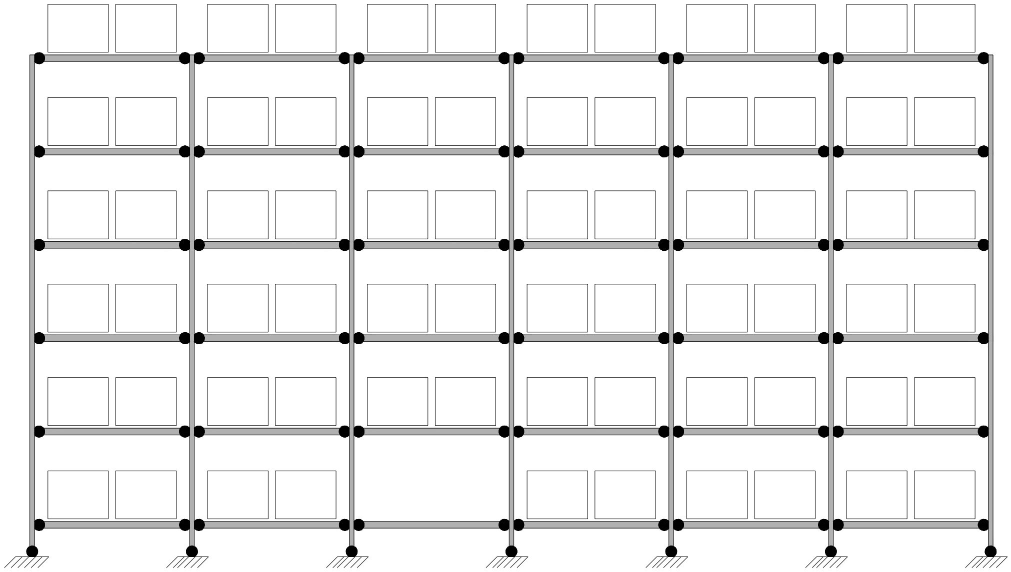


(h) case 7

Figure 3 (continued). Cases of loading

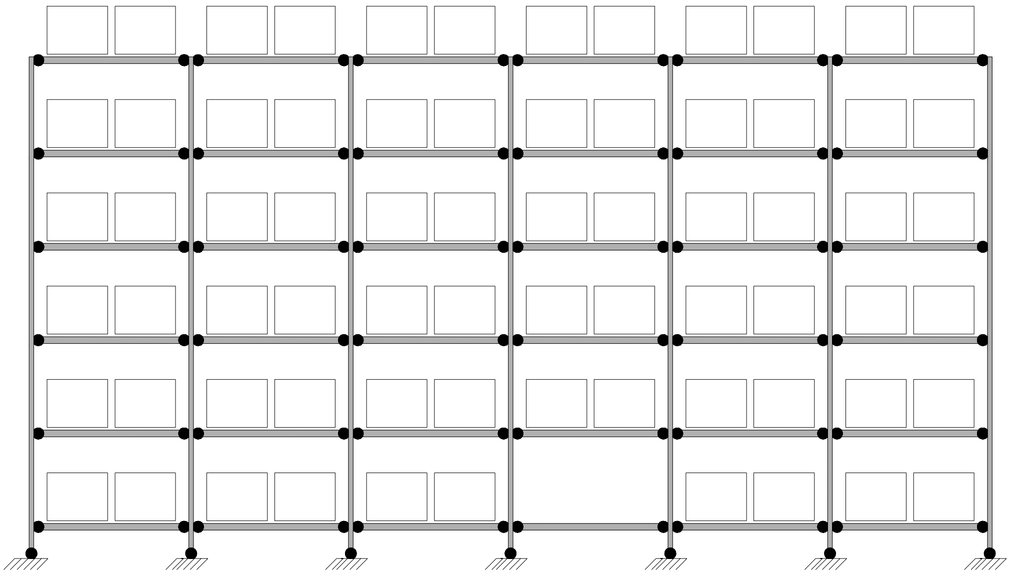


(i) case 8

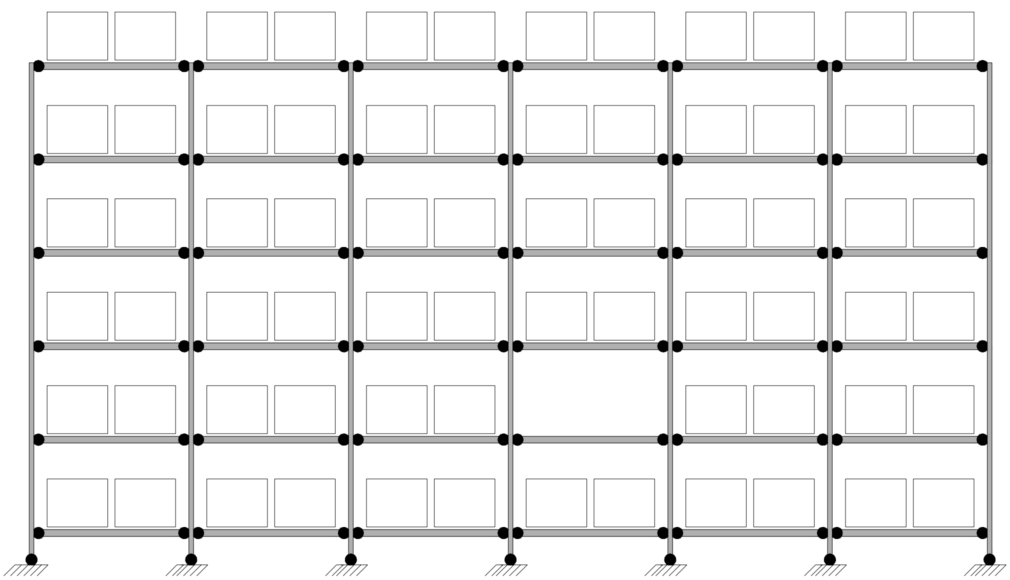


(j) case 9

Figure 3 (continued). Cases of loading

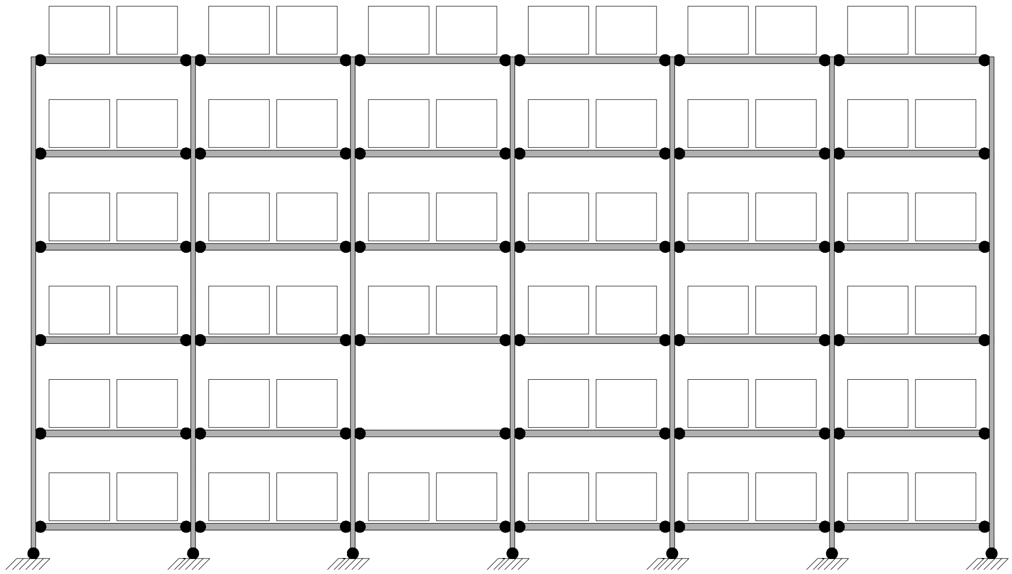


(k) case 10



(l) case 1

Figure 3 (continued). Cases of loading



(m) case 12

Figure 3 (continued). Cases of loading

From the figures it can be seen that without any imperfection that the pairs of load cases are usually mirror images and would give the same results. However, when the geometrical imperfections in the down and cross-aisle directions were added the symmetry was lost and the cases therefore show the effects of the asymmetry.

3.3 Frame imperfection

According to the FEM code [10] the effects of frame imperfections can be considered in the analysis of pallet rack structures by means of an initial out-of-plumb (*i.e.* initial sway imperfection) or by a closed system of equivalent horizontal forces. In this study the sway imperfections ϕ were replaced by a closed system of equivalent horizontal forces. These equivalent horizontal forces were applied at each level and were proportional to the factored vertical loads applied to the structure at the corresponding level as shown in Figure 4.

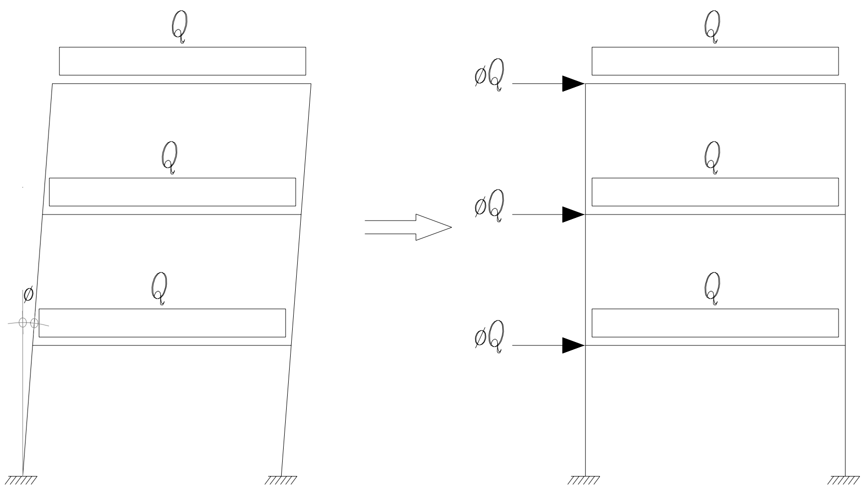


Figure 4. Equivalent horizontal forces

A uniformly distributed load of 1 N/m was applied to each beam, and frame imperfections were considered by assigning lateral point loads at each level with a magnitude of 1% of the applied vertical load.

3.4 Beam, Upright, Base-plate and Bracing Element and Cross Section

The numerical study on the frame was carried out by using a non-linear Finite Element package ABAQUS/CAE [16].

ABAQUS offers a wide range of beam elements and cross sections including "Eluer-Brenoulli"-type beams and "Timoshenko" type beams with solid, thin walled closed and thin-walled open sections.

The general beam section with Timoshenko-type beam (B31) is selected as the suitable section and element in the library of ABAQUS software.

3.4.1 Major Beam Element Type in ABAQUS Library

The main types of beam element are:

Eluer-Brenoulli (slender) beams

Eluer-Brenoulli beams are. These elements do not allow for transverse shear deformation; plane sections initially normal to the beam's axis remain plane (if there is no warping) and normal to the beam axis. They should be used only to model slender beams.

Timoshenko (shear flexible) beams

Timoshenko beams (B21, B22, B31, B31OS, PIPE22, PIPE32, and their "hybrid" equivalents) allow for transverse shear deformation. They can be used for thick ("stout") as well as slender beams.

ABAQUS assumes that the transverse shear behavior of Timoshenko beams is linear elastic with a fixed modulus and, thus, independent of the response of the beam section to axial stretch and bending.

3.4.2 Major Cross Section Type in ABAQUS Library

The main types of Cross Section element are:

Solid cross sections

For solid sections under bending, plane (beam) sections remain plane. Under torsional loading any noncircular beam section will warp: the beam section will not remain planar

Nonsolid (thin-walled) cross sections

In ABAQUS nonsolid sections are treated as “thin-walled” sections; that is, in the plane of the section, the thickness of a branch of the section is assumed to be small compared to its length. Thin-walled beam theory determines the shear in the wall of the section depending on whether the section is closed or open.

Closed sections

A closed section is a nonsolid section whose branches form closed loops. Closed sections offer significant resistance to torsion and do not warp significantly.

Open sections

An open section is a nonsolid section with branches that do not form closed loops, such as an I-section or a U-section. In such sections the shear stress is assumed to vary linearly over the wall thickness and to vanish at the center of the wall.

3.4.3 General Beam Section

Beam general section is used to define linear or non-linear beam section response when numerical integration over the section is required. In this case ABAQUS precomputes the beam quantities such as area, moments of inertia and torsional rigidity and perform all section computations during the analysis in terms of the precomputed values. This method combines the functions of beam section and material descriptions (a material definition is not needed).

These elements have two translational and one rotational degrees of freedom $(\Delta_x, \Delta_y and \theta_z)$ at each end and also include the effects of shear flexibility. Each beam member was divided to 24 elements, the bottom upright member was divided into 8 elements and other upright members were divided to 28 elements (the length of each element was 100 mm and the length of each upright element was 50 mm. Typical section values representative of real rack structures were used in the analyses Table 1 show the values used in the analysis.

Table 1. Section properties

Member	Beams	Uprights
Area (mm^2)	45.0	57.5
Second Moment of Area, down-aisle (mm^4)	$0.78 * 10^6$	$0.60 * 10^6$
Second Moment of Area, cross-aisle (mm^4)	$0.32 * 10^6$	$0.20 * 10^6$
Torsion Constant (mm^4)	$1.10 * 10^6$	$0.80 * 10^6$
Young's Elastic Modulus, N/mm^2	$210 * 10^9$	$210 * 10^9$

3.4.4 Truss Elements

The members forming the horizontal and diagonal bracing were analysed using truss elements type T3D2 (2-node linear displacement) with cross sectional area 90 mm^2, these elements are slender structural members that can transmit only axial force and do not transmit moments.

3.4.5 Shell Elements

The base-plate was analysed using shell element type S4R (4-node doubly curved thin shell). The area of this base-plate was taken be (150 * 150 mm) with a total thickness of 3 mm and each base-plate was divided into 64-elements. In addition these elements have three translational and three rotational degrees of freedom at each node.

3.5 Convergence study

This convergence study was carried out with the aim of determining the required number of elements that were needed for the finite element model for the beam and shell elements. Moreover for each element type different numbers of element were used and the effect of on the displacements of the models upper node investigated.

3.5.1 Beam element

Figure 5 shows a plot of the different number of elements (4, 6, 24 and 28-elements) used for the beams. The load-deflection curves are plotted for each number of elements for the general case of a fixed-base with no imperfection. As the reader can see this figure showed good agreement between the use of 24-elements and 48-elements for the same frame with a maximum percentage error of 0.01%. Hence the number of elements used in the analysis for all cases was 24.

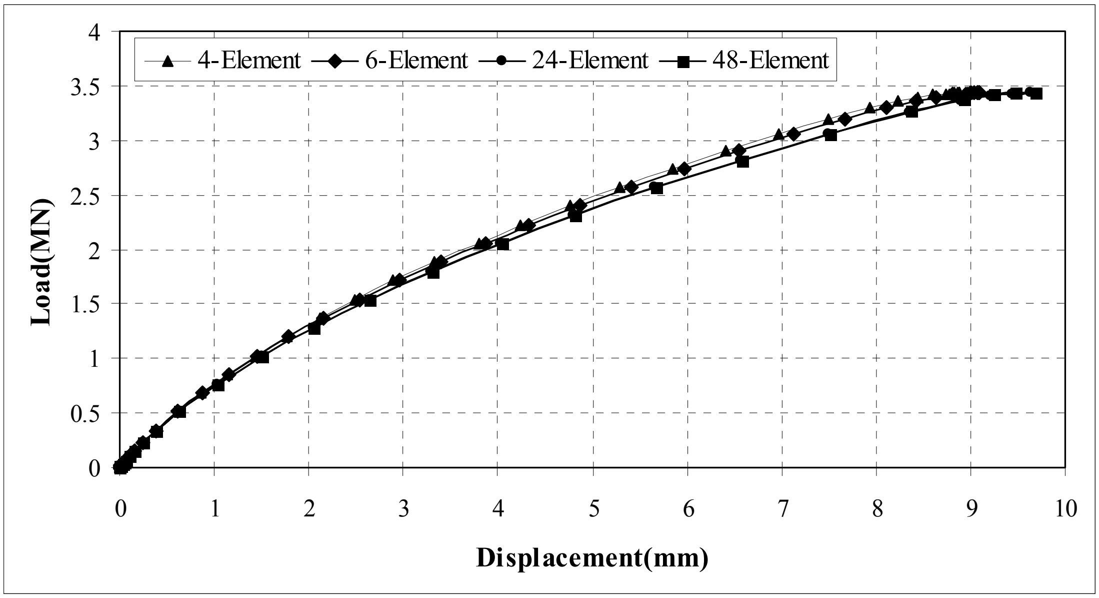


Figure 5. Load-Displacement curves for different number of elements

3.5.2 Shell element

Figure 6 shows the different number of elements (4, 16, 36, 64 and 100-elements) that were used for shells and the load-deflection curves are plotted for each discretisation for the general case semi-rigid base-plate with no imperfection.

This figure shows that when 4 and 16-shell element were used the frame swayed in the negative down-aisle direction and when 36, 64 and 100-shell elements were used the frame swayed in the opposite direction. As no imperfections in either load or geometry occurred in the test model the direction of sway was arbitrary. In addition the use of 36, 64 and 100-shell elements gave a good agreement between them with a maximum percentage error of 0.007%. So this means that finer meshes help to obtain accurate results. It was found that discretising the base-plate to 64-element gave sufficient, accurate results.

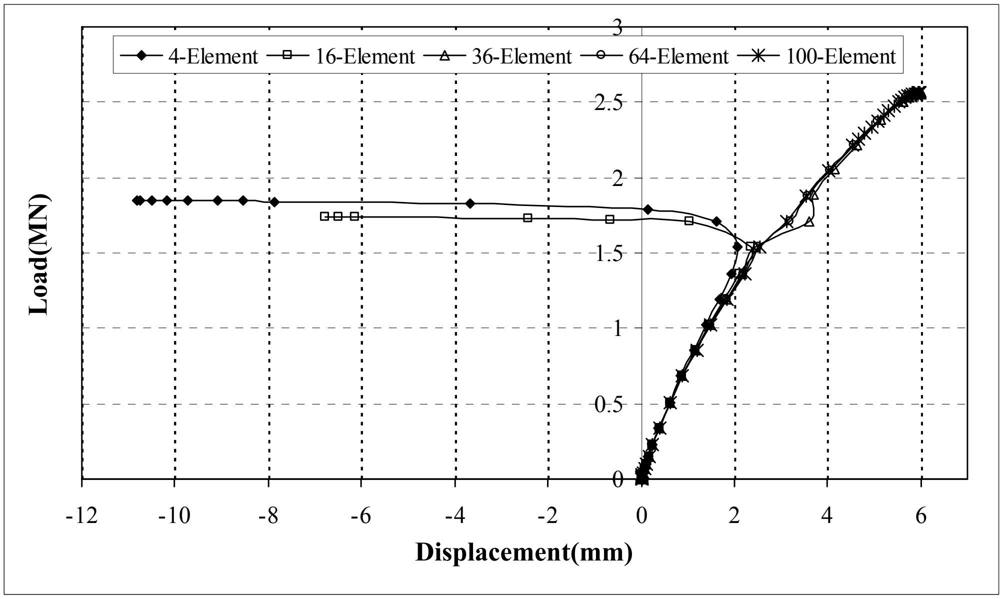


Figure 6. Load-Displacement curves for different numbers of elements

3.6 Semi-rigid Connections:

Semi-rigid connections were used to connect uprights and beams, and uprights and base-plates. Modeling the semi-rigid connection between the uprights and beams and uprights and base-plates required using a special type element that represents the required stiffnesses.

The SPRING2 element that shown in figure 3.1 is selected as the best spring element in the library of ABAQUS software.

3.6.1 Spring Element Library

In order to create the spring element properties three-type can be used. These are:

SPRINGA :

Axial spring between two nodes, whose line of action is the line joining the two nodes. This line of action may rotate in large-displacement analysis. In this type the active degrees of freedom are 1, 2 and 3.

1. SPRING1:

   Spring between a node and ground, acting in a fixed direction. In this type the active degrees of freedom are 1, 2, 3, 4, 5 and 6.

2. SPRING2 :

   Spring between two nodes, acting in a fixed direction. In this type the active degrees of freedom are 1, 2, 3, 4, 5 and 6.

3.6.2 SPRING2 Element

Spring elements can be define in two different way :

- Can couple a force with a relative displacement;
- Can couple a moment with a relative rotation .

The terms "force" and "displacement" are used throughout the description of spring elements. When the spring is associated with displacement degrees of freedom, these variables are the force and relative displacement in the spring. If the springs are associated with rotational degrees of freedom, they are torsional springs; these variables will then be the moment transmitted by the spring and the relative rotation across the spring. In addition the spring behavior can be linear or non-linear in any spring elements in ABAQUS.

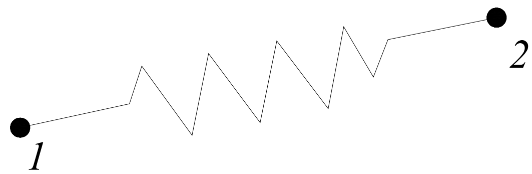


Figure 3.1 SPRING2

The joint element used to model the beam-upright connection had three translational and three rotational degrees of freedom at each end. The translational stiffnesses of the connection were taken to be infinite. The rotation stiffness about an axis along a cross-aisle direction $(z-\text{axis})$ was taken to be 0.15 * 10^6 kNmm/rad. The rotation stiffness about a vertical axis $(y-\text{axis})$ was assumed to be zero, and about an axis lying along the beam $(x-\text{axis})$ was taken to be infinite.

The joint element used to model the upright-base plate connection such upright-beam connection had three translational and three rotational degrees of freedom at each end. The translational stiffnesses of the connection were taken to be infinite. The rotation stiffness about axis along a cross-aisle direction $(z-\text{axis})$ was taken to be 0.15 * 10^6 kNmm/rad . The rotation stiffness about a vertical axis $(y-\text{axis})$ was taken to be infinite, and about an axis lying along the beam $(x-\text{axis})$ was taken to be 0.30 * 10^6 kNmm/rad.

Chapter Four

RESULTS AND DISCUSSION

The responses of the fixed, semi-rigid and pinned-base pallet rack structures under 36-load combinations are investigated and compared by computing several variables such as proportional load factor, lateral displacement and reaction forces.

For each load case a static analysis was conducted followed by non-linear geometric analysis to obtain the maximum load that the structure can carry. The frame was subjected to vertical load and an investigation undertaken into the influence of the initial imperfection as a side load at the corresponding beam level on the frame. In this study there are three-main type of load combinations, without initial imperfection (UDL only), with initial imperfection in down-aisle direction (UDL+1% x load) and with initial imperfection in down and cross-aisle directions (UDL+1% x +1% z load). It was found that from the results that the two cases for down-aisle imperfection and down and cross-aisle imperfection the behaviour of the structure are very close to each other.

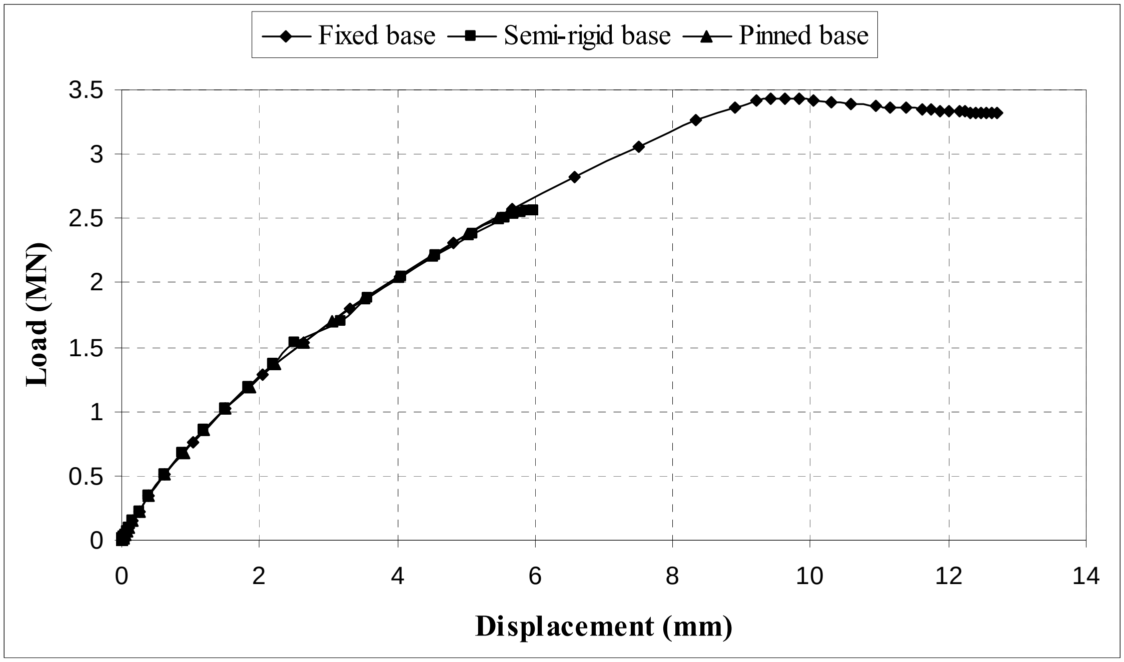
4.1 Without initial imperfection cases

In order to investigate the behaviour of a pallet rack when it is subjected to cases of loading with different type of base fixation (fixed, semi-rigid and pinned base), the horizontal displacement of the upper left node in the model is plotted versus load capacity of the frame.

Figures 7(a) - 7(h) show the effect of cases of loading on the displacement of the model's upper node under different base condition. Moreover each figure includes 3-curves for rigid, semi-rigid and pinned base. From figures 7(a) - 7(h) it seen that the frames reached their maximum capacity when it is totally fixed. And then, it is compared with the frames when the base conditions are semi-rigid and pinned base. As a result from these figures the frame with general case and when the base condition are semi-rigid and pinned base losses 25% of there load capacity with reference to the rigid base. On the other hand for cases 2, 3 and 6 the frame losses 25% of their load capacity when the base condition is semi-rigid and 29% with pinned base, but in case 7 and 8 the frame losses 32% and 55% with semi-rigid base and 20% and 31% with pinned base, finally with case 10 and 12 the frame losses 25% of their load capacity when the base condition is semi-rigid and 55% when it is pinned base. From these results it is clearly seen that the reduction of the frame capacity when the base condition is pinned base is higher than semi-rigid base for all cases of loading except case 7 and 8 and this occur due to the way of arrange the loading (removing the loading on alternative levels) and without presence of any initial imperfection in down and/or cross aisle direction which is lead the frame to sway with down aisle but in the opposite direction.

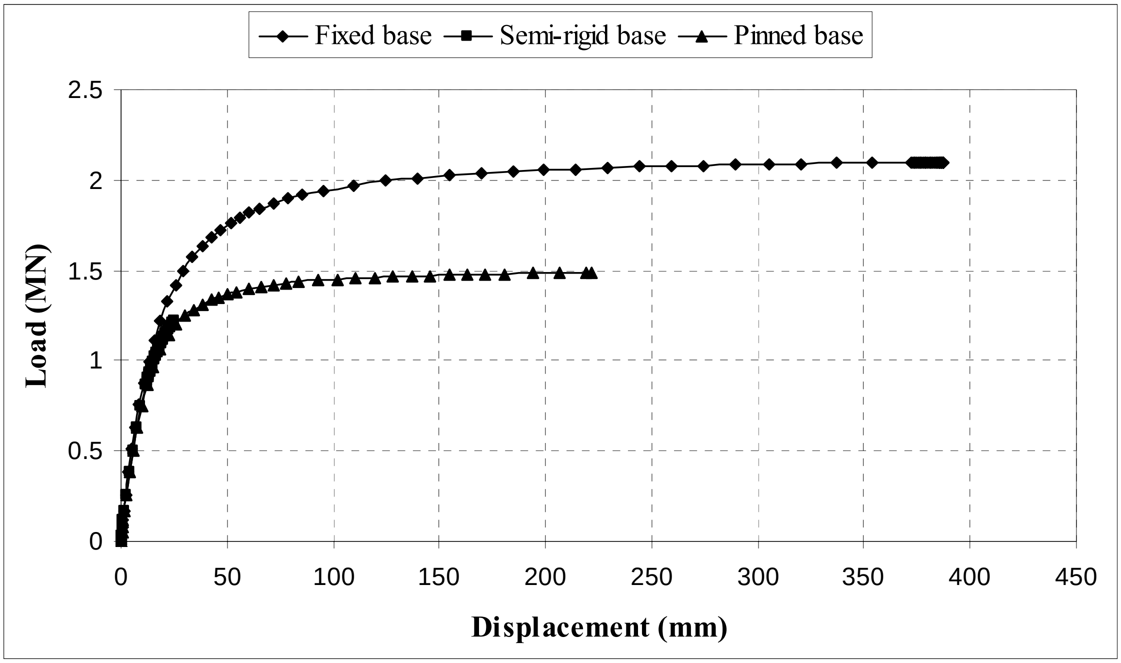
Figures 8(a), 7(b) and 8(c) show the effects of different base conditions on the displacements of the model's upper left node under different combinations. From figures 8(a) and 8(c) frames with fixed and pinned bases reached their maximum capacity when they was partially loaded under load case 8. The frame with a semi-rigid base-plate reached its maximum capacity when it was fully loaded (general case) and with no imperfection. The maximum reduction from the fully loaded case was 44%. The effects of small imperfections on the maximum capacity can be clearly seen. The full details of maximum loads in each load case compared against the fully loaded case and the reaction forces in each column of the frame are given in tables 2-4. The percentage increases/reductions in capacity are compared against the fully loaded case for each imperfection condition.

Figure 9 shows the total reaction force in the columns calculated by the summation of reaction force in all columns; these values show good agreement with the total load capacity for each cases of loading. In addition Figure 10 shows the collapse mode for the critical case (case 2).

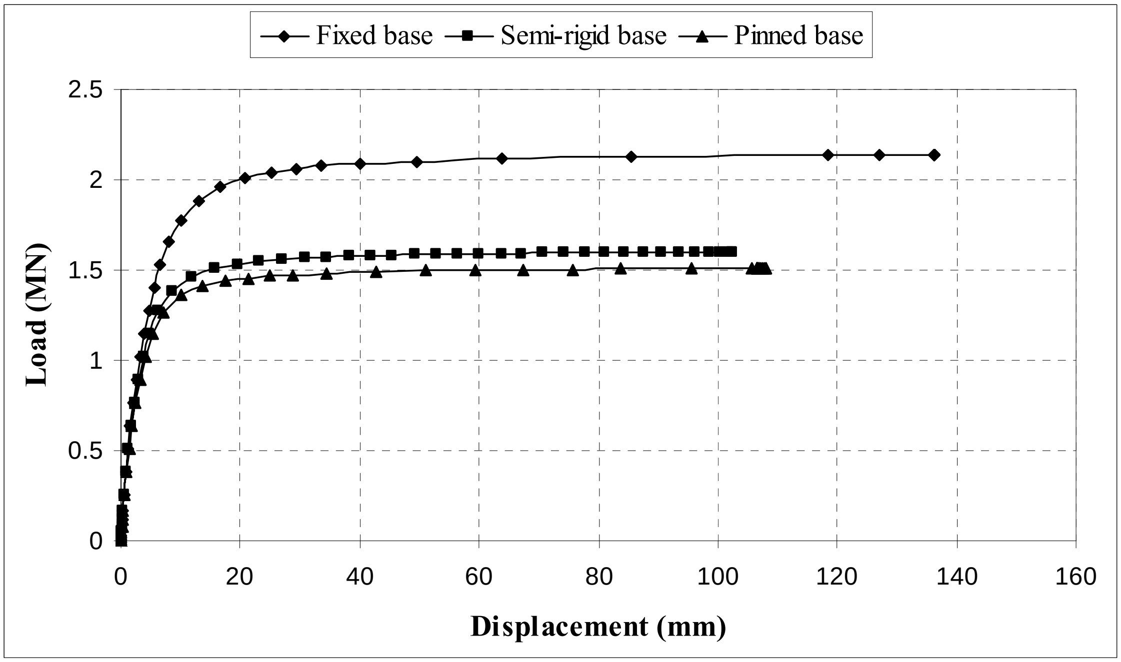


(a) General Case

Figure 7 Load-Displacement curves for rigid, semi-rigid and pinned base

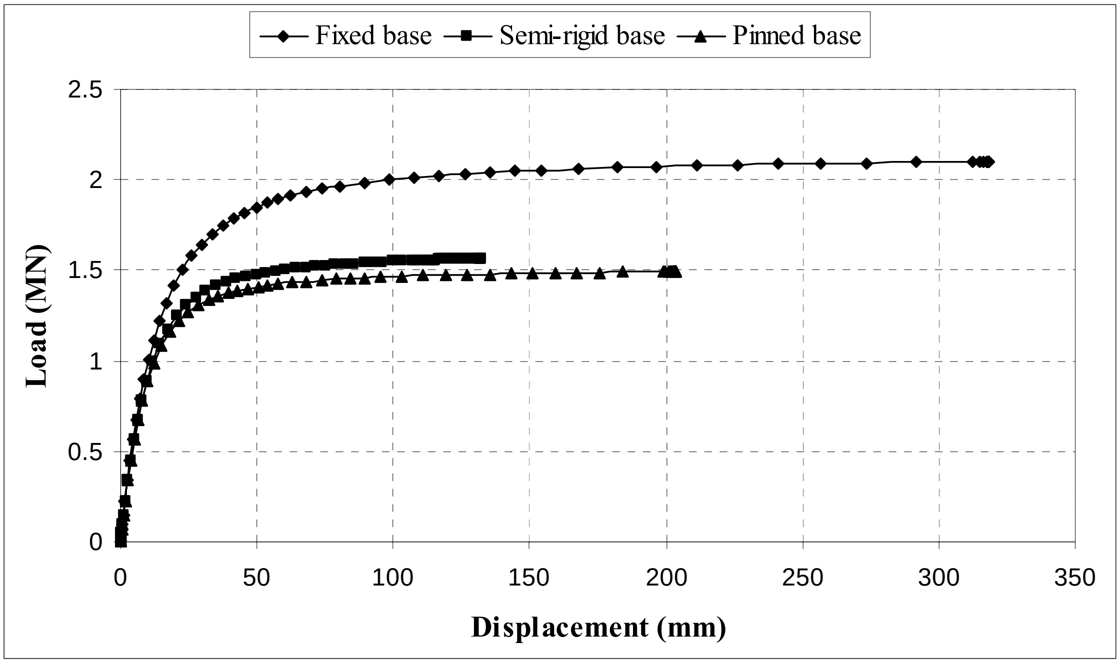


(b) Case 2

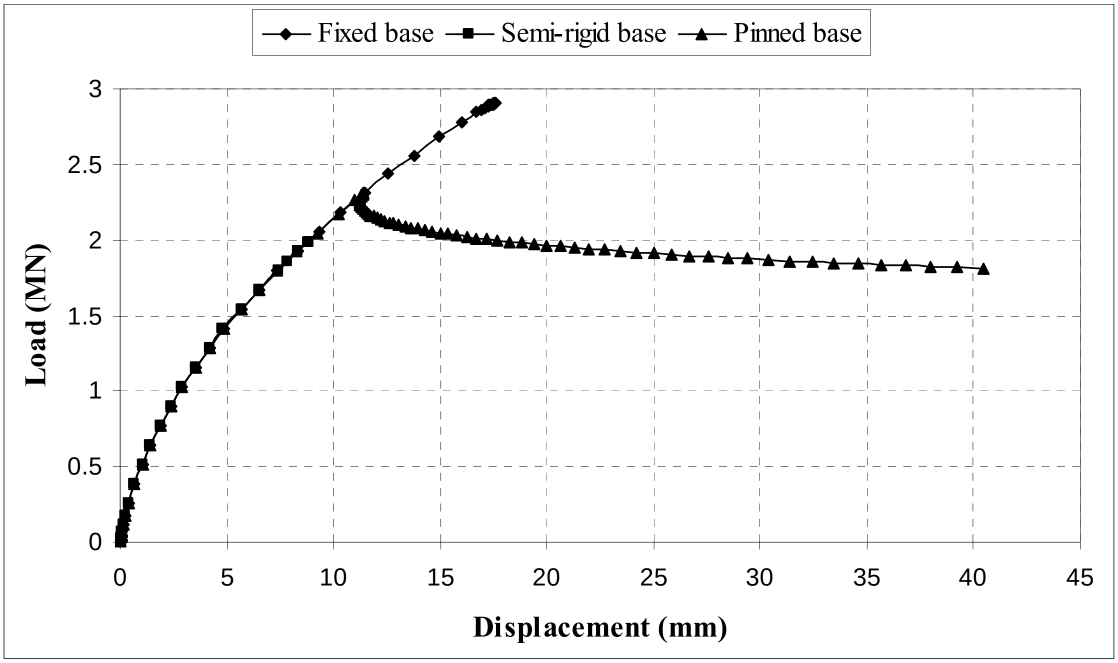


(c) Case 3

Figure 7(continued). Load-Displacement curves for rigid, semi-rigid and pinned base

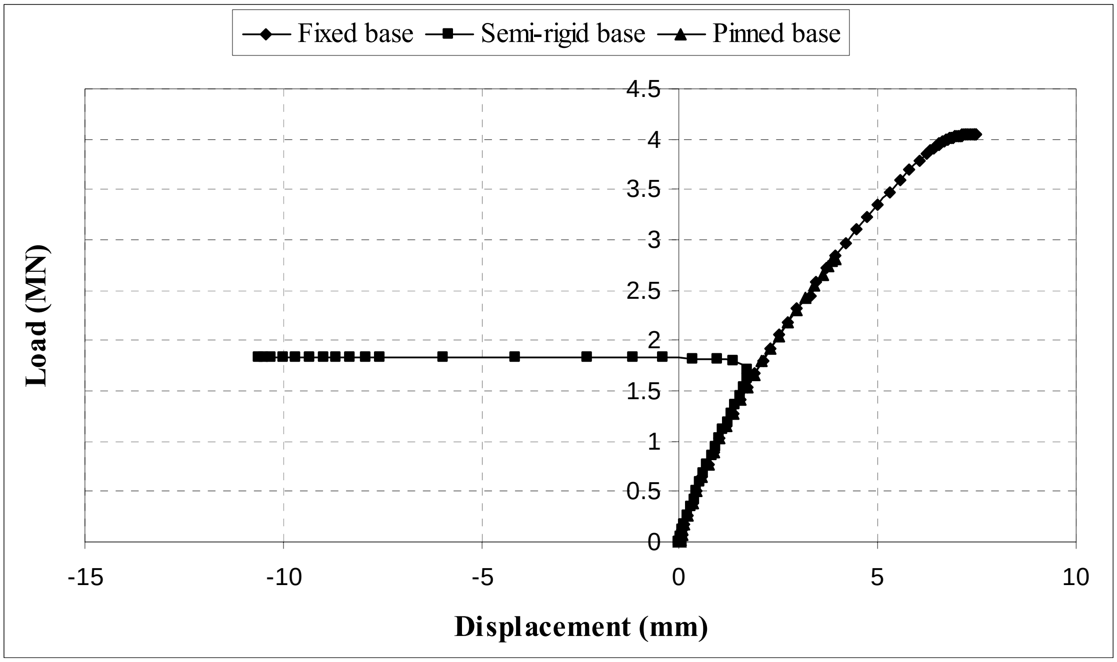


(d) Case 6

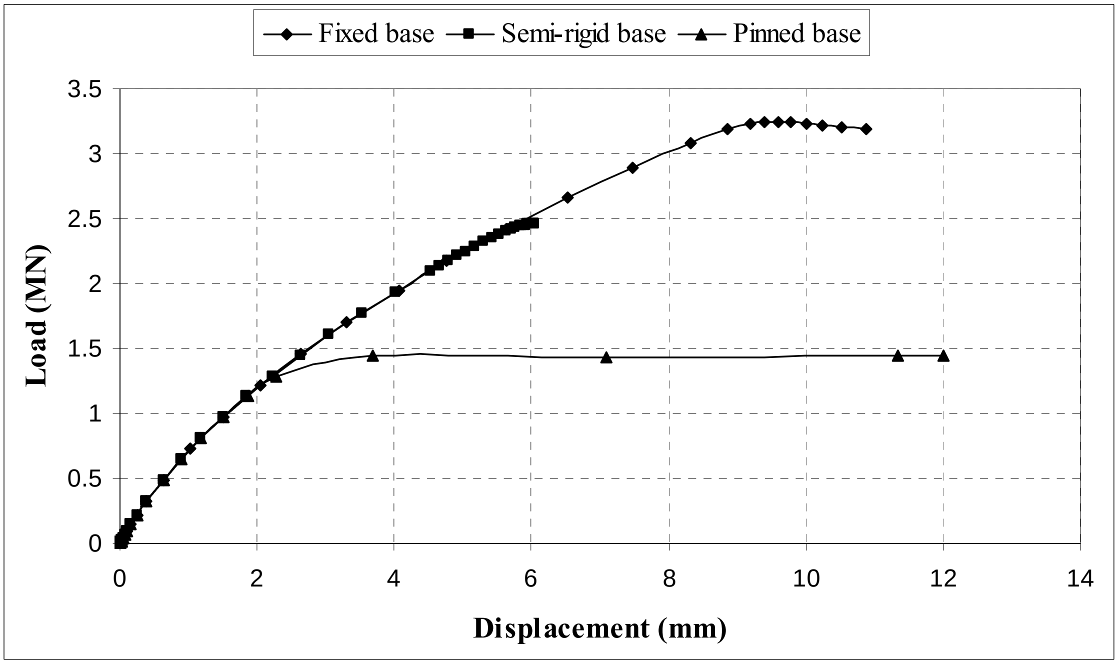


(e) Case 7

Figure 7(continued). Load-Displacement curves for rigid, semi-rigid and pinned base

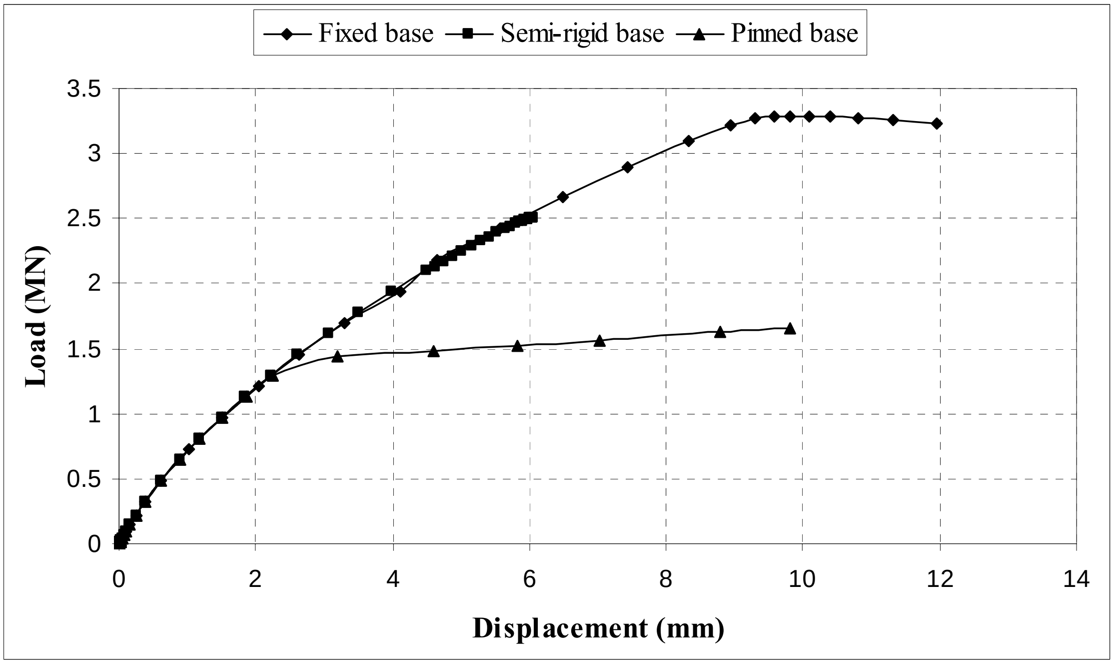


(f) Case 8



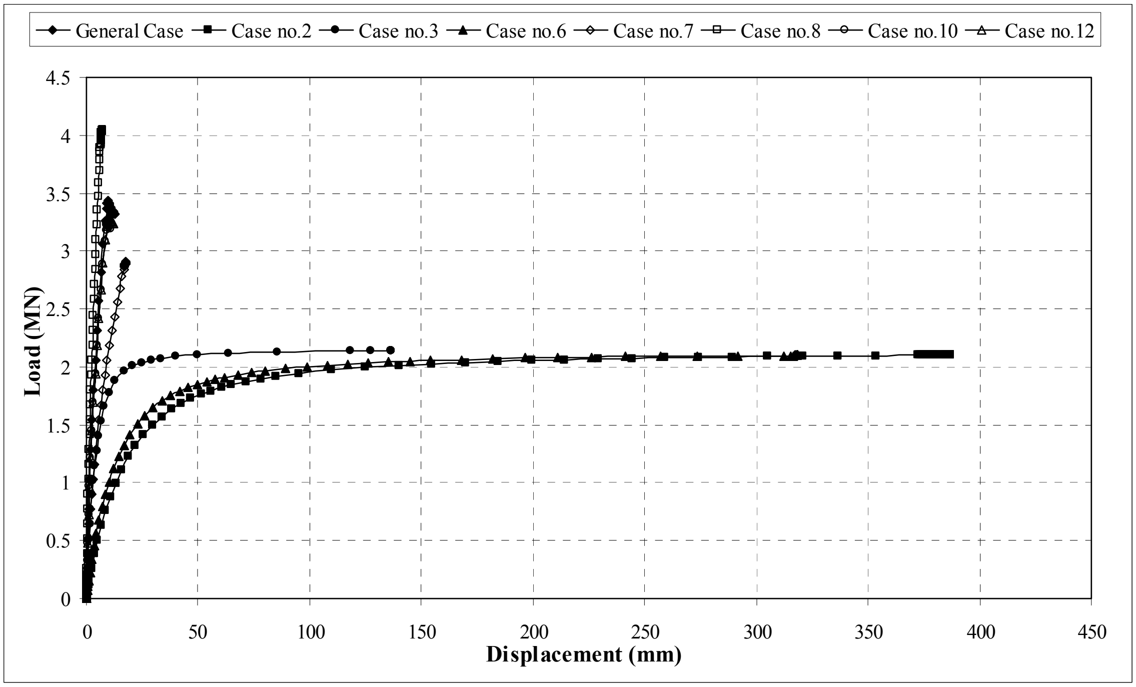
(g) Case 10

Figure 7(continued). Load-Displacement curves for rigid, semi-rigid and pinned base



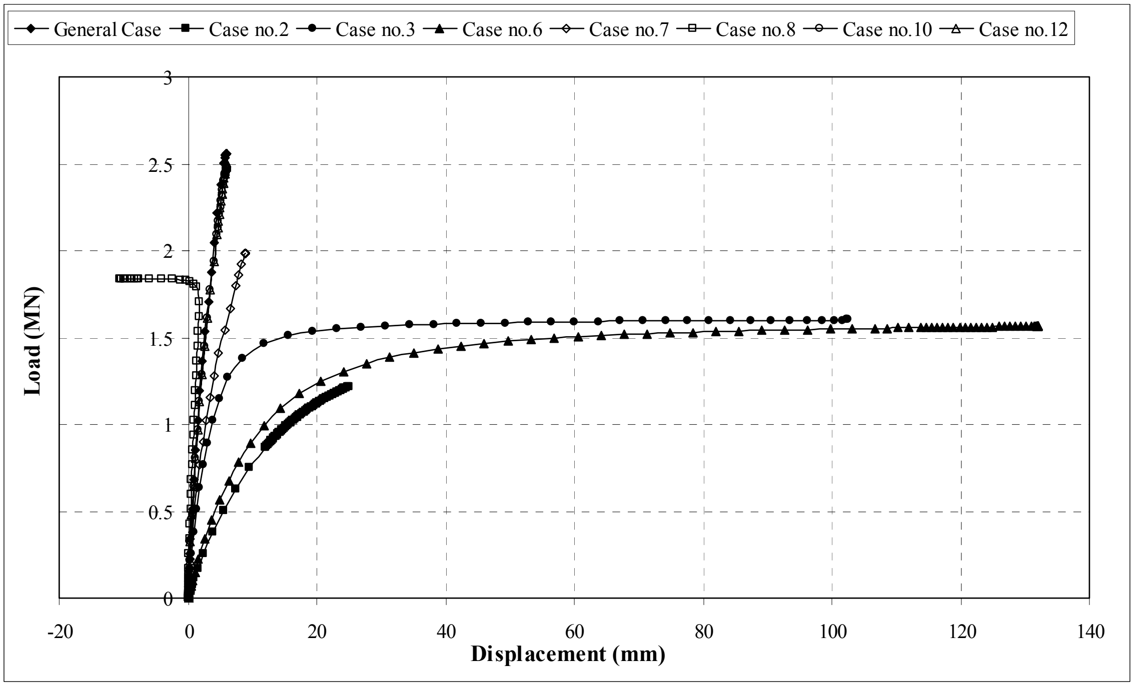
(h) Case 12

Figure 7(continued). Load-Displacement curves for rigid, semi-rigid and pinned base



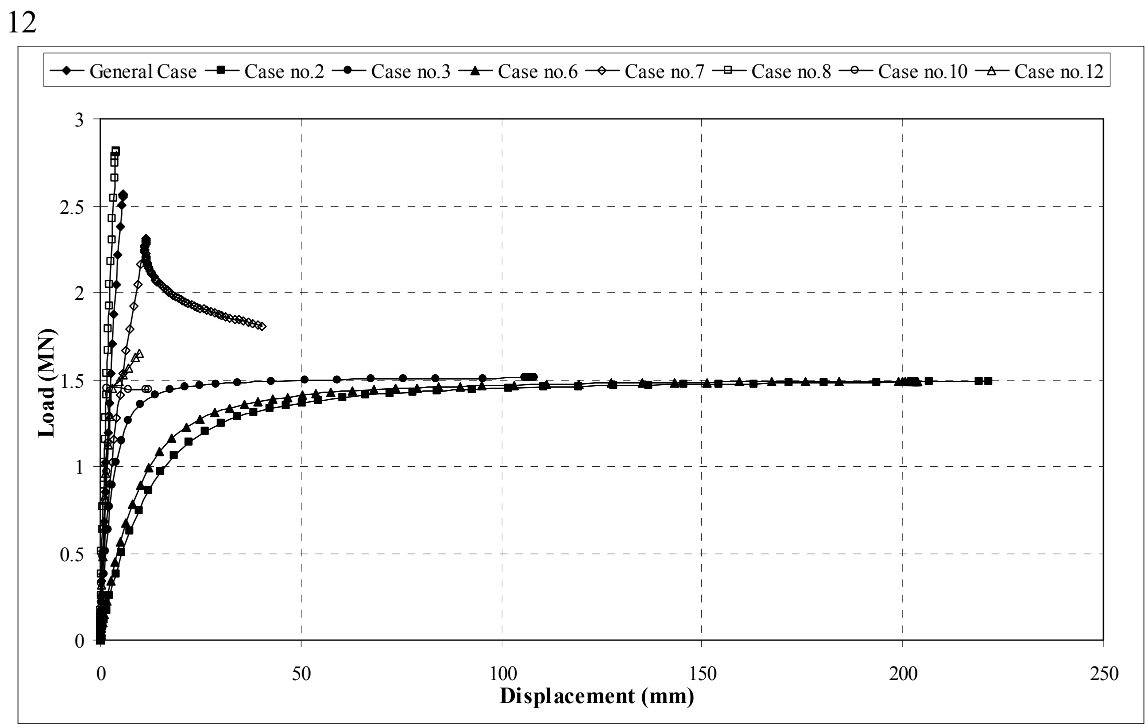
(a) Rigid Base

Figure 8. Load-Displacement curve for all cases



(b) semi-rigid base

Figure 8 (continued). Load-Displacement curve for all cases



(c) Pinned base

Figure 8 (continued). Load-Displacement curve for all cases

Table 2. Influence of cases of loading on the rigid-base frame

Load case	Maximum load capacity of the frame (kN)	% of the load capacity of the General case	Maximum load in columns (kN)						
			col.1	col.2	col.3	col.4	col.5	col.6	col.7
General case	3432.1		147.141	292.618	300.439	302.423	300.650	292.667	147.255
Case No.1	2099.1	-38.84%	188.650	175.497	175.545	175.474	175.553	171.616	-9.503
Case No.2	2099.2	-38.83%	-9.420	171.609	175.503	175.497	175.510	175.540	188.507
Case No.3	2136.9	-37.74%	86.156	176.408	178.486	178.427	178.449	176.750	94.665
Case No.4	2137.2	-37.73%	94.735	176.809	178.487	178.453	178.522	176.444	86.082
Case No.5	2097.7	-38.88%	144.823	259.518	134.148	134.180	259.423	131.236	-7.977
Case No.6	2098.1	-38.87%	-7.955	131.269	259.267	134.254	134.216	259.461	144.848
Case No.7	2904.6	-15.37%	124.664	247.515	253.214	254.295	253.626	248.027	124.831
Case No.8	4047.3	17.93%	172.633	341.953	349.655	351.545	349.587	341.334	172.759
Case No.9	3244.2	-5.47%	147.253	292.793	276.394	278.522	300.905	292.991	147.400
Case No.10	3244.3	-5.47%	147.290	292.961	300.718	278.395	276.756	292.829	147.370
Case No.11	3290.5	-4.12%	149.119	295.834	275.723	278.086	306.913	299.555	150.099
Case No.12	3290.9	-4.11%	149.947	299.626	306.728	278.352	275.816	295.922	149.255

Table 3. Influence of cases of loading on the semi-rigid base-plate frame

Load case	Maximum load capacity of the frame (kN)	% of the load capacity of the General case	Maximum load in columns (kN)						
			col.1	col.2	col.3	col.4	col.5	col.6	col.7
General case	2560.2		109.585	213.118	214.536	214.071	214.491	213.370	109.504
Case No.1	1570.5	-38.7%	139.072	131.848	131.813	131.859	131.802	128.921	-4.656
Case No.2	1568.8	-38.73%	-1.478	128.421	131.302	131.551	121.613	131.651	128.310
Case No.3	1601.1	-37.5%	63.876	132.813	134.630	134.338	134.586	133.024	72.665
Case No.4	1600.8	-37.5%	72.916	133.230	134.373	134.592	134.418	133.027	63.476
Case No.5	1578.8	-38.3%	109.310	194.667	101.648	101.542	195.662	99.372	-5.850
Case No.6	1564.4	-38.9%	-2.013	98.486	193.397	100.368	100.521	193.298	104.966
Case No.7	1988.3	-22.3%	84.770	165.194	167.160	167.145	167.127	165.117	84.829
Case No.8	1840.1	-28.1%	78.196	152.988	154.504	154.518	154.525	153.096	78.386
Case No.9	2459.6	-3.9%	111.498	217.214	198.771	199.367	217.969	216.909	111.398
Case No.10	2458.6	-4.0%	111.418	216.578	218.381	198.043	199.876	216.996	111.350
Case No.11	2504.5	-2.2%	113.544	220.471	205.731	203.544	221.416	220.658	113.470
Case No.12	2504.3	-2.2%	113.540	220.270	221.188	204.109	204.048	220.961	113.464

Table 4. Influence of cases of loading on the pinned-base frame

Load case	Maximum load capacity of the frame (kN)	% of the load capacity of the General case	Maximum load in columns (kN)						
			col.1	col.2	col.3	col.4	col.5	col.6	col.7
General case	2563.0		109.564	213.355	214.211	214.458	214.829	213.331	109.574
Case No.1	1487.9	-41.9%	132.591	124.703	124.777	124.760	124.792	122.107	-5.438
Case No.2	1488.1	-41.9%	-5.401	122.065	124.781	124.740	124.772	124.683	132.571
Case No.3	1509.3	-41.1%	50.548	125.026	126.456	126.462	126.435	125.179	67.793
Case No.4	1550.6	-39.5%	125.900	128.170	130.025	130.051	130.090	128.601	6.852
Case No.5	1534.0	-40.1%	154.083	187.942	98.821	99.234	188.421	96.740	-5.789
Case No.6	1491.3	-41.8%	-5.374	93.781	184.211	95.844	95.802	184.178	102.997
Case No.7	2311.3	-9.8%	98.279	190.756	191.467	190.685	191.278	190.505	98.164
Case No.8	2813.1	9.8%	120.440	235.760	237.970	237.828	237.996	235.908	120.602
Case No.9	1450.4	-43.4%	65.374	127.401	118.047	118.043	128.770	127.419	64.644
Case No.10	1450.8	-43.4%	65.461	127.458	128.808	118.078	118.078	127.433	65.398
Case No.11	1448.9	-43.5%	66.356	128.586	119.360	119.359	129.975	128.729	65.795
Case No.12	1465.0	-42.8%	65.805	128.714	129.960	119.345	119.345	128.568	66.330

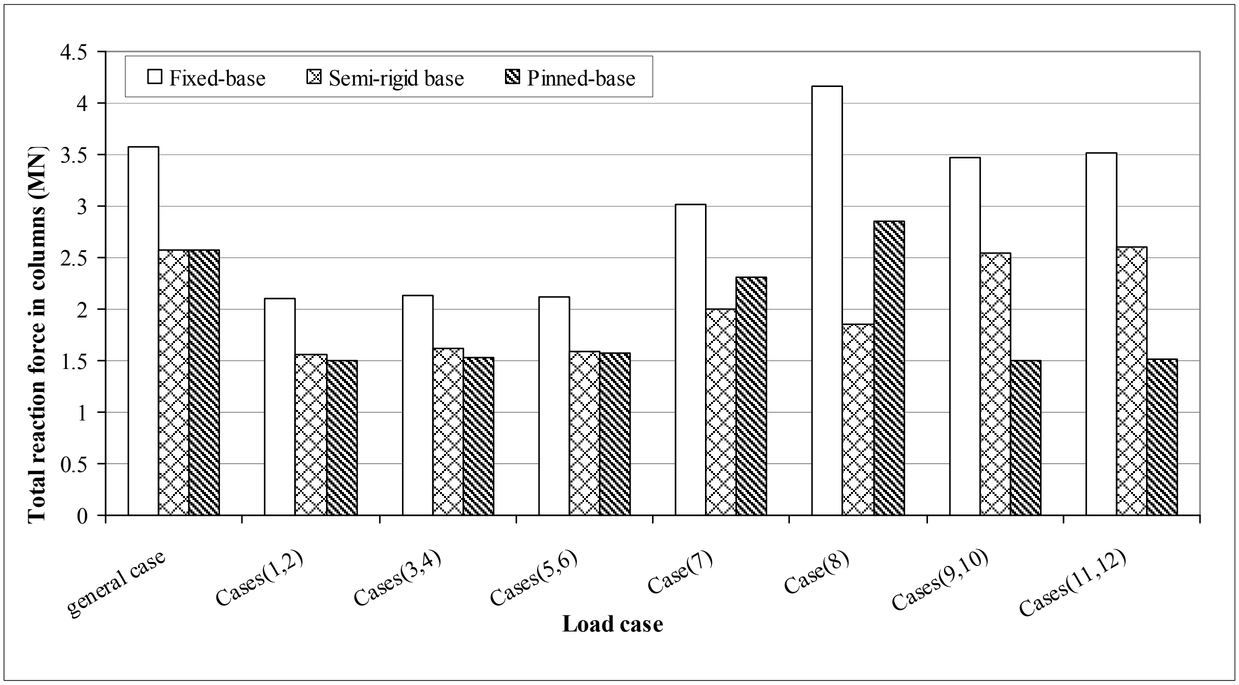
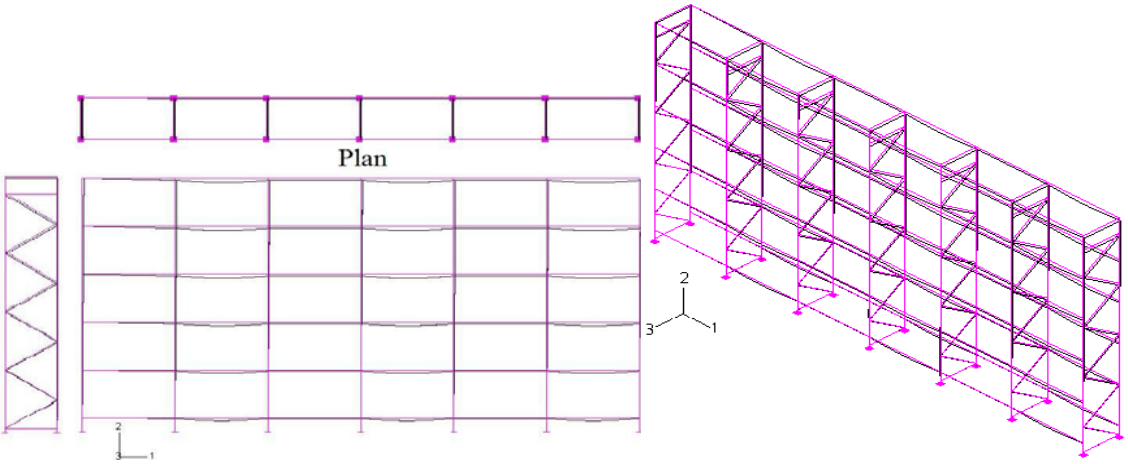


Figure 9. Total reaction force in columns for all cases with no imperfection



Front elevation Isometric view

Figure 10. Collapse mode for case 2 (semi-rigid base-plate frame)

4.2 Imperfection in down and cross-aisle directions

In order to investigate the behaviour of a pallet rack when it is subjected to cases of loading and geometrical imperfection in both down and cross-aisle directions with different type of base fixation (fixed, semi-rigid and pinned base), the horizontal displacement of the upper left node in the model is plotted versus load capacity of the frame. The value of the initial imperfection is equal to 1% of the vertical load in down and cross-aisle directions at the corresponding beam level.

Figures 11(a) - 11(h) show the effect of cases of loading on the displacement of the model's upper node under different base condition. Moreover each figure includes 3-curves for rigid, semi-rigid and pinned base. From figures 11(a) - 11(h) it seen that the frames reached their maximum capacity when it is totally fixed. And then, it is compared with the frames when the base condition is semi-rigid and pinned base.
As a result from these figures the frame with general case and when the base condition is semi-rigid losses 27% of there load capacity and 30% with pinned base with reference to rigid base. On the other hand for cases 2, 3, 6 and 7 and when the base condition is semi-rigid the frame losses 28% of their load capacity and 30% with pinned base. But for case 8 the frame losses 31% of their load capacity when the base conditions are semi-rigid and pinned base. Finally for case 10 and 12 the frame losses 27% of their load capacity when the base condition is semi rigid base and 30% when it is pinned base. From these result it is clearly seen that the reduction in the frame capacity for semi-rigid and pinned base with reference to the rigid base is slightly close to each other up to 31% and under a certain combination of presence this imperfection and load cases base-plates fail earlier

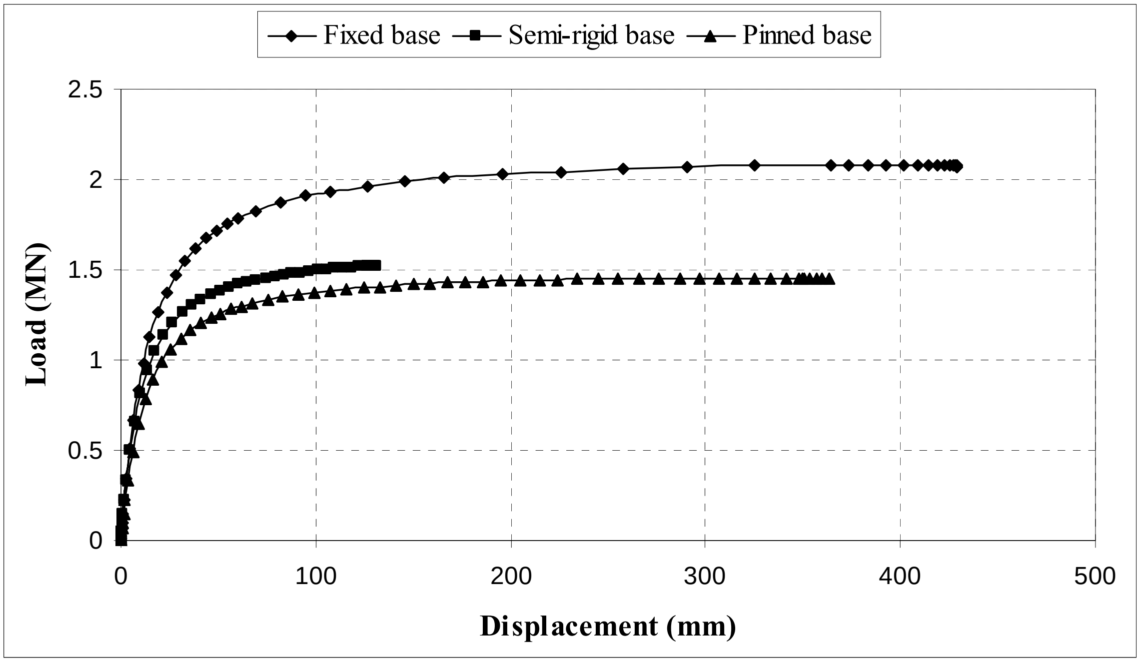
than rigid and pinned base. In addition the presence of the initial imperfection in down and cross-aisle directions reduce the difference in the frame load capacity between the semi-rigid and pinned base.

Figures 12(a), 12(b) and 12(c) show the reductions in capacities of the frames when subjected to geometrical imperfections in down and cross-aisle directions for the same node as used in figure 11. These figures show 7-different combinations of loading in addition to the general fully loaded case for (rigid, semi-rigid and pinned bases respectively).

As can be seen in figures 12(a), 12(b) and 12(c) the frames reached their maximum capacity when they were partially loaded, normally case 8. The minimum capacity, below that of the loaded frame was usually either case 11 or case 12 which has one element in the lowest bay unloaded in conformance with the common loadings used in design (see Beale and Godley [10, 11]). The full details of maximum loads in each load case compared against the fully loaded case and the reaction force in each column of the frame are given in tables 5-8. The percentage increases/reductions in capacity are compared against the fully loaded case for each imperfection condition.

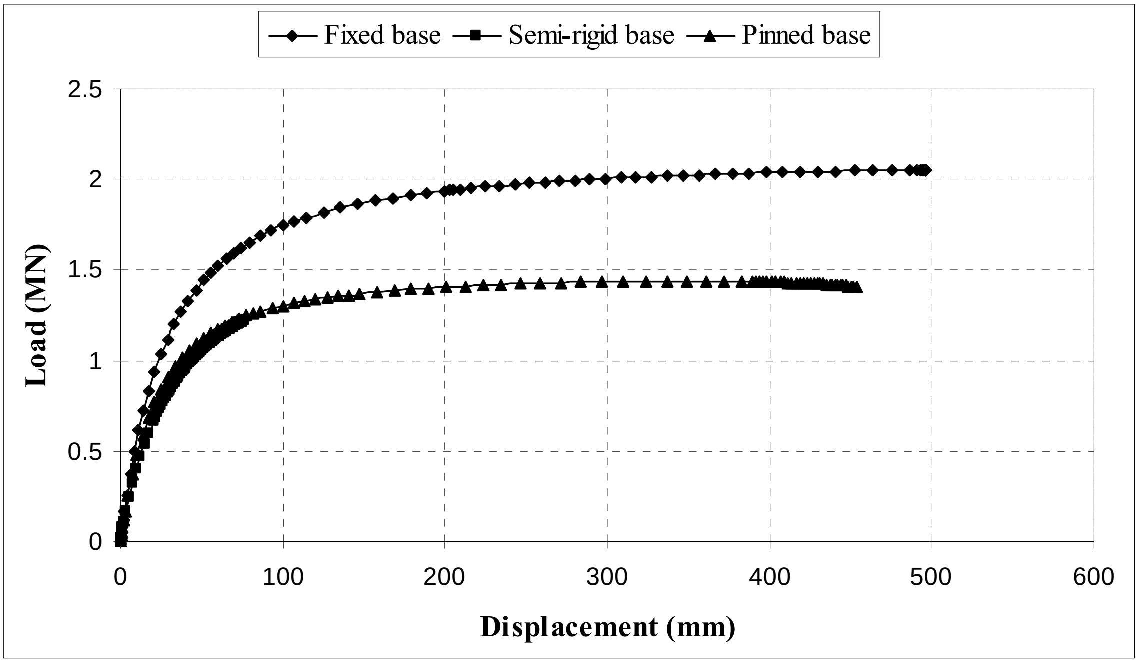
Figures 13 shows the total reaction force in the columns calculated by the summation of reaction force in all columns; these values have shown good agreement with total load capacity for each cases of loading. In addition Figure 14 shows the collapse mode for the case 7.

In all cases analysed the effects of imperfections in reducing the maximum load carrying capacity of frames is clearly seen. Whether the imperfections are caused by geometric imperfection or load asymmetry the frames capacity is reduced by up to 45% of the fully loaded perfect frame. In addition, the load deflection plots show that the failure in the perfect frame is by structural instability with a steep descending curve.

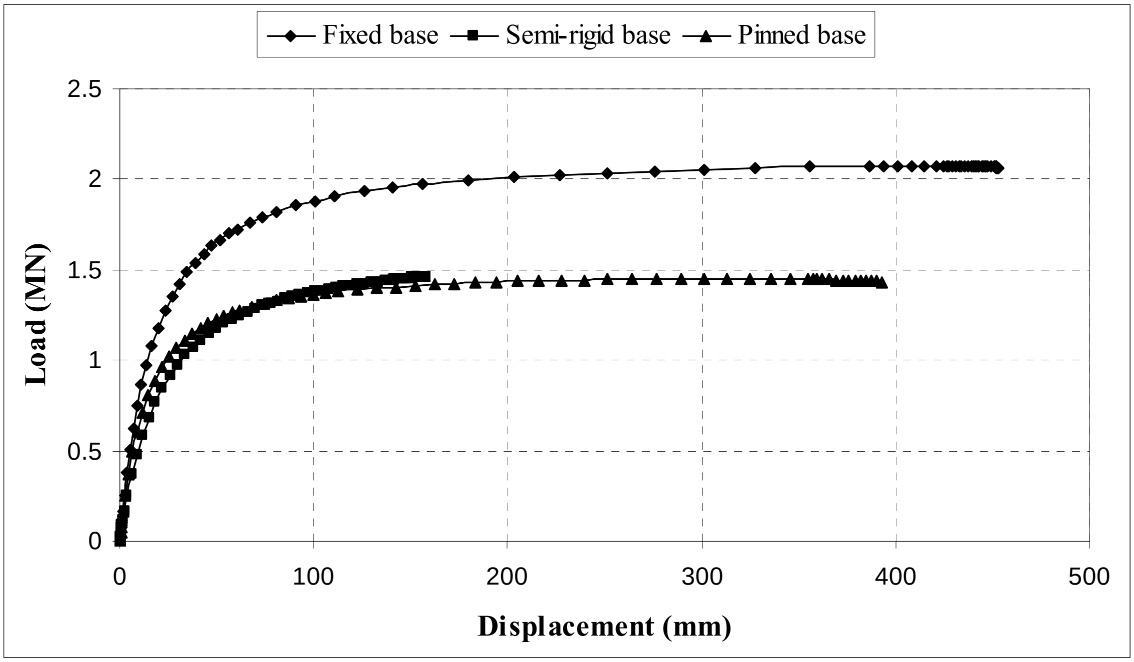


(a) General Case

Figure 11. Load-Displacement curves for rigid, semi-rigid and pinned base

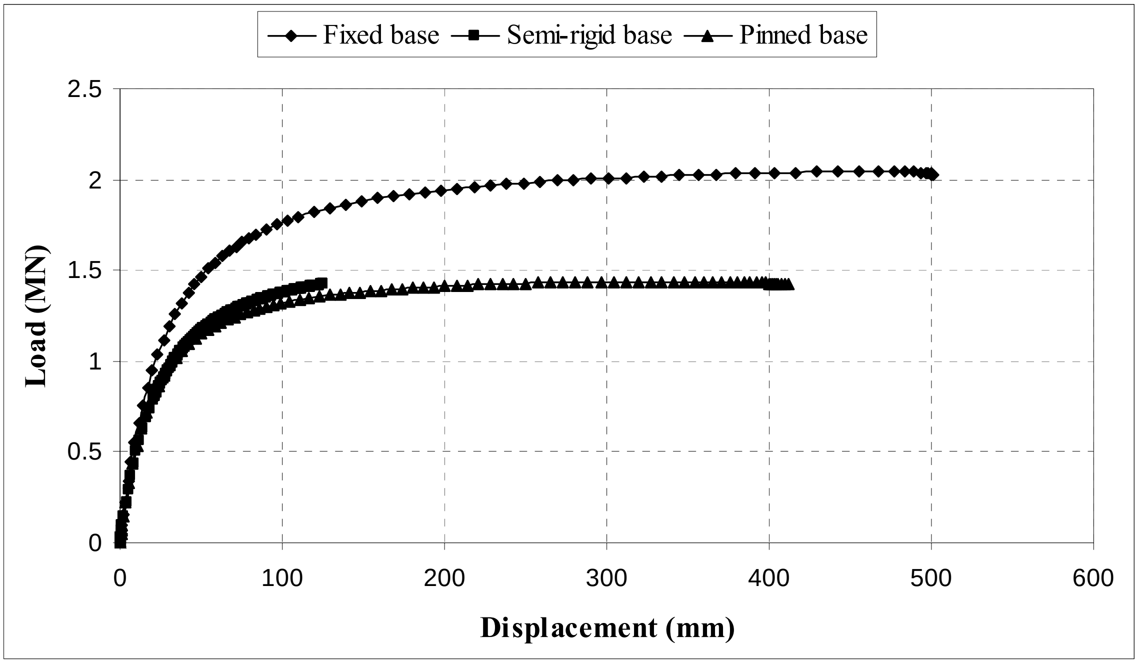


(b) Case 2

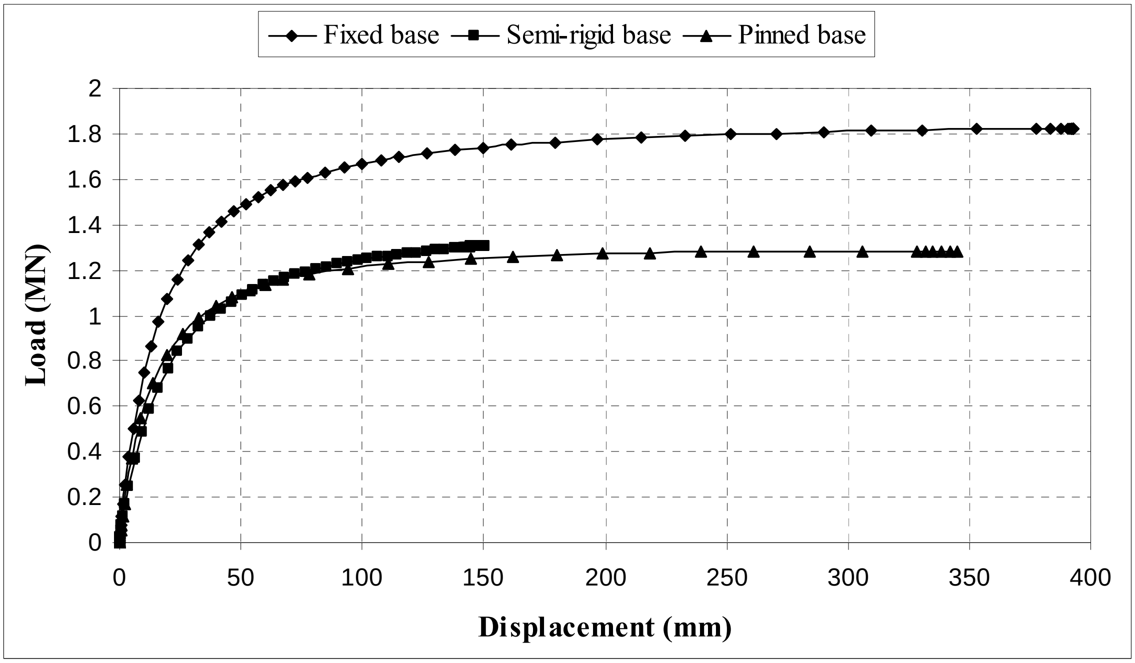


(c) Case 3

Figure 11(continued). Load-Displacement curves for rigid, semi-rigid and pinned base

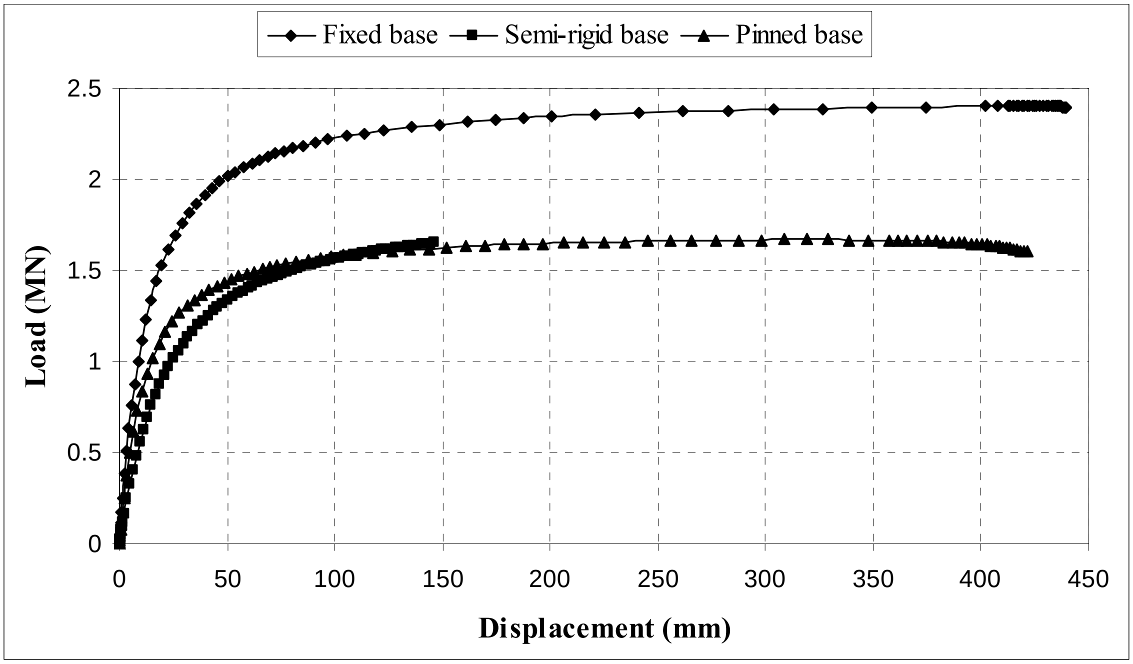


(d) Case 6

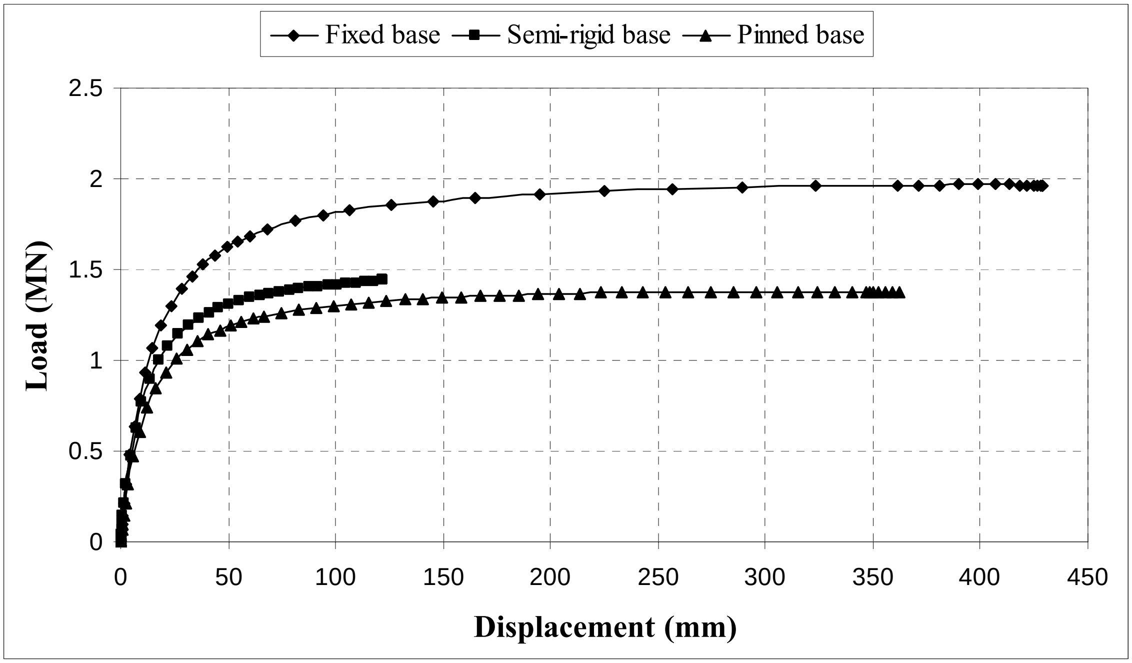


(e) Case 7

Figure 11(continued). Load-Displacement curves for rigid, semi-rigid and pinned base

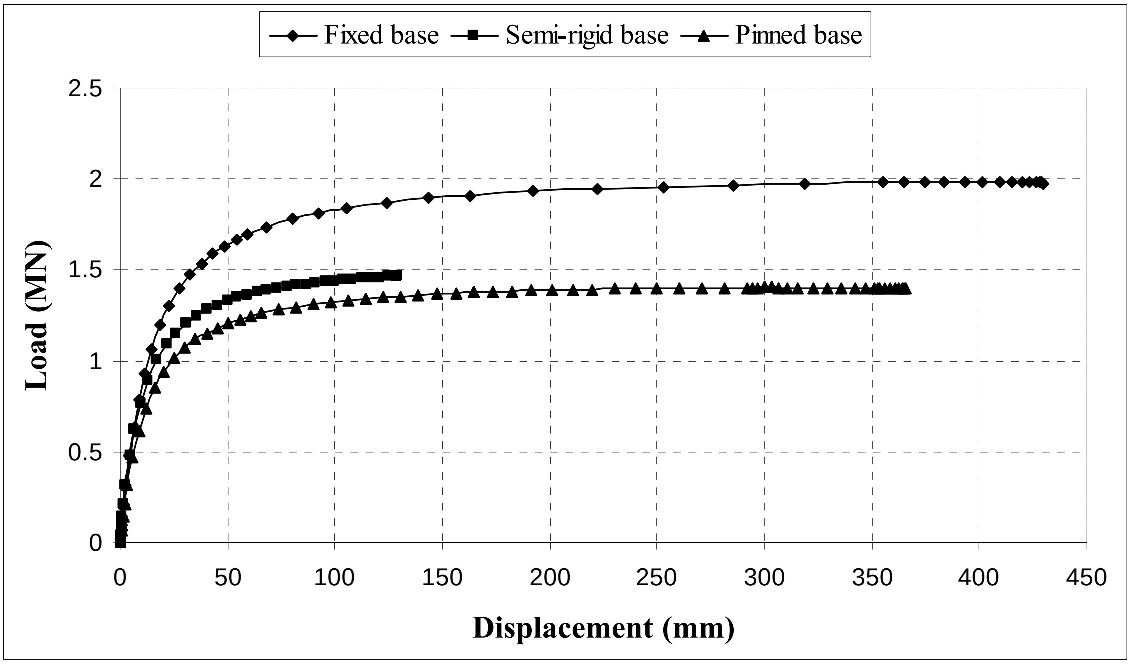


(f) Case 8



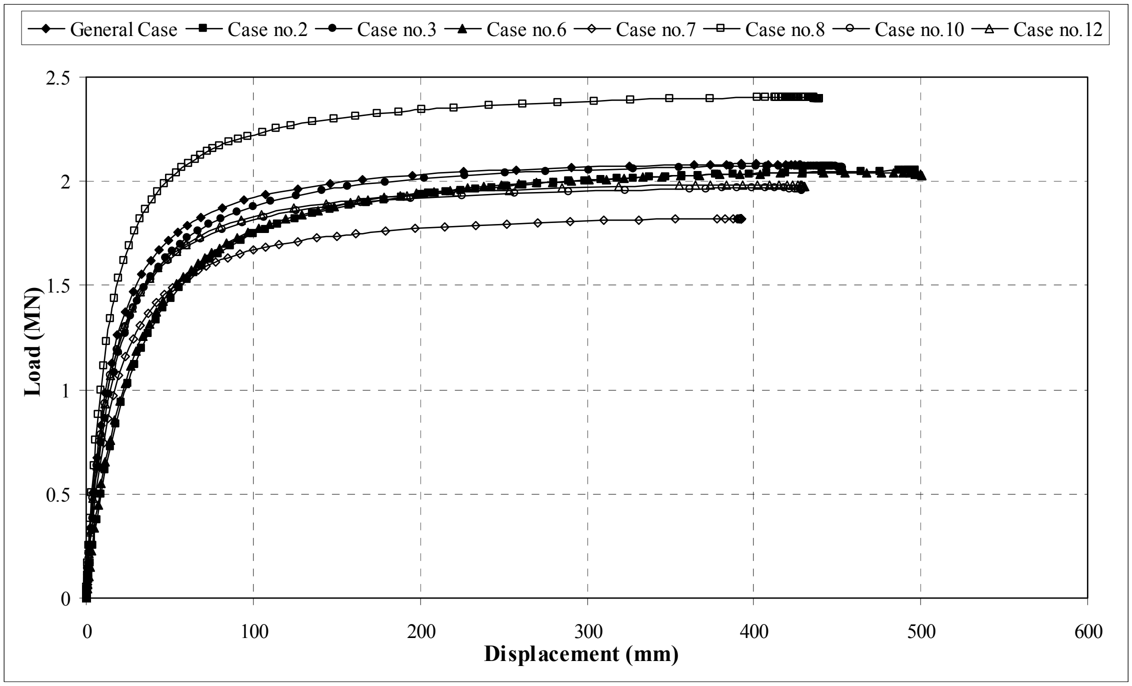
(g) Case 10

Figure 11(continued). Load-Displacement curves for rigid, semi-rigid and pinned base



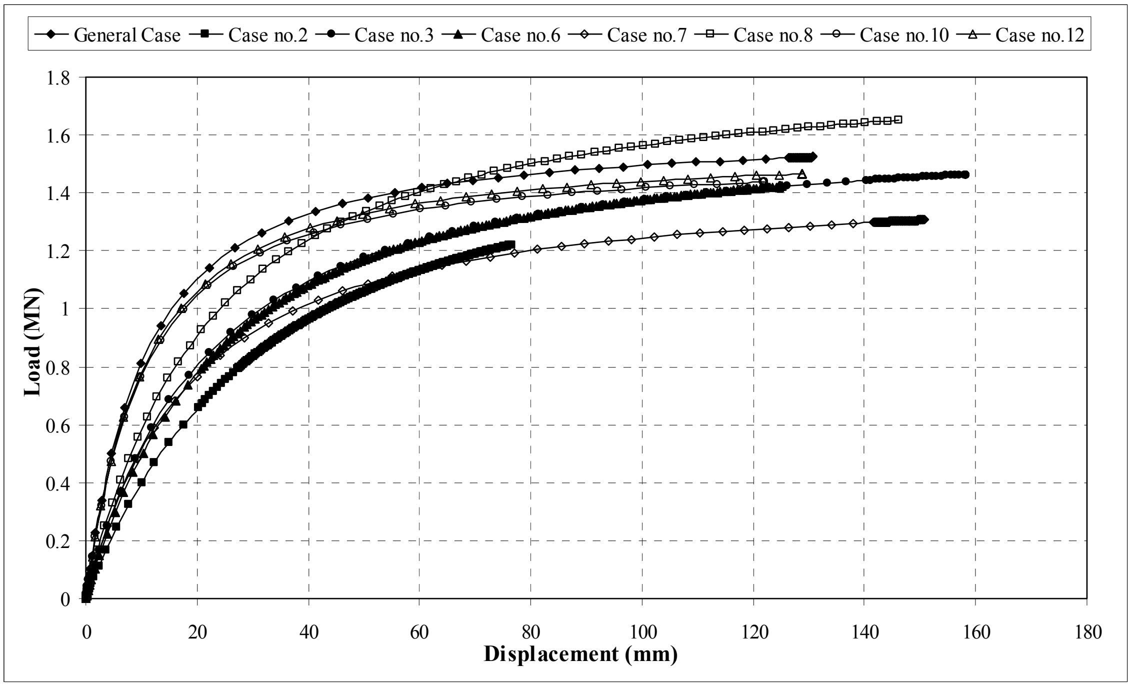
(h) Case 12

Figure 11(continued). Load-Displacement curves for rigid, semi-rigid and pinned base



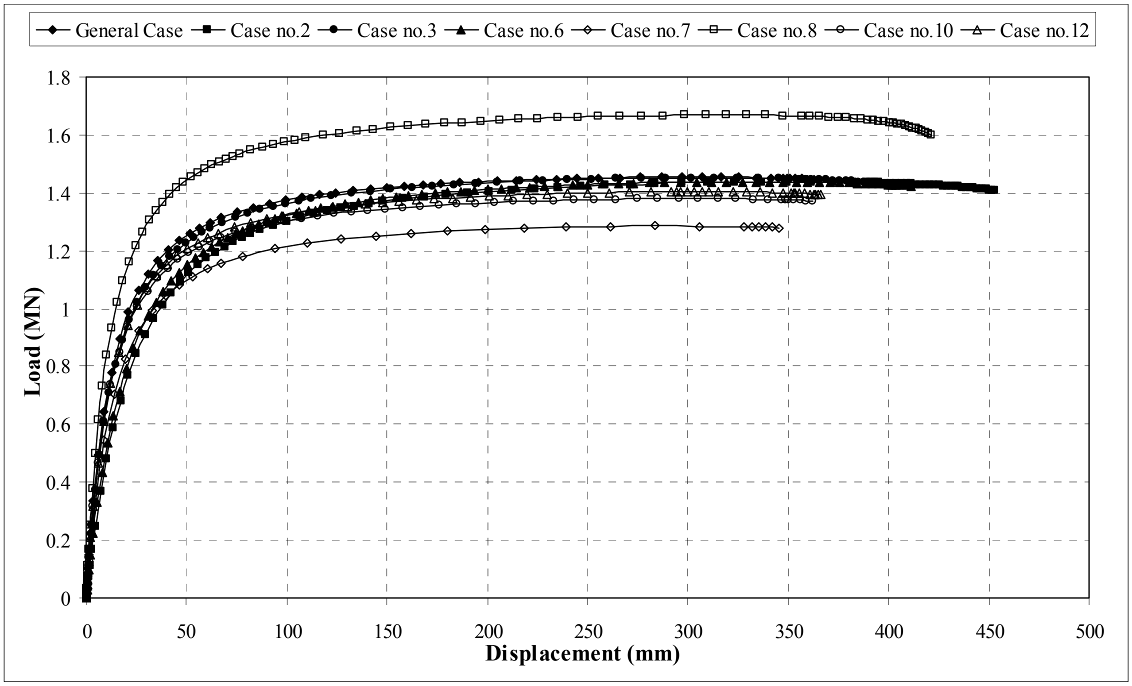
(c) Rigid Base

Figure 12. Load-Displacement curves for all cases with side imperfection



(d) semi-rigid base

Figure 12(continued). Load-Displacement curves for all cases with side imperfection



(c) Pinned base

Figure 12(continued). Load-Displacement curves for all cases with side imperfection

Table 5. Influence of cases of loading on the rigid-base frame

Load case	Maximum load capacity of the frame (kN)	% of the load capacity of the General case	Maximum load in columns (kN)						
			col.1	col.2	col.3	col.4	col.5	col.6	col.7
General case	2082.4		76.297	175.511	177.643	177.700	177.723	175.787	103.682
Case No.1	2109.8	1.3%	175.322	179.674	179.785	179.678	179.797	175.753	10.085
Case No.2	2051.0	-1.5%	-12.566	170.799	174.880	175.249	175.059	175.443	192.090
Case No.3	2074.6	-0.4%	75.781	174.744	177.168	177.143	177.255	175.533	104.965
Case No.4	2083.0	0.0%	76.989	176.003	177.765	177.869	177.811	175.751	103.873
Case No.5	2089.0	0.3%	127.253	264.036	136.050	136.035	264.159	133.129	10.639
Case No.6	2042.8	-1.9%	-12.436	131.108	258.105	133.685	134.540	258.534	149.507
Case No.7	1822.8	-12.5%	65.754	154.229	156.340	156.407	156.418	154.474	92.443
Case No.8	2401.7	15.3%	89.072	201.765	203.966	204.016	204.019	202.005	117.551
Case No.9	1967.0	-5.5%	76.370	175.497	163.125	163.193	177.680	175.770	103.600
Case No.10	1967.0	-5.5%	76.373	175.511	177.620	163.178	163.210	175.740	103.601
Case No.11	1985.3	-4.7%	77.105	176.969	164.642	164.685	179.113	177.427	104.542
Case No.12	1985.1	-4.7%	77.097	176.952	164.710	164.667	179.089	177.402	104.528

Table 6. Influence of cases of loading on the semi-rigid base-plate frame

Load case	Maximum load capacity of the frame (kN)	% of the load capacity of the General case	Maximum load in columns (kN)						
			col.1	col.2	col.3	col.4	col.5	col.6	col.7
General case	1524.1		60.642	128.211	129.53	129.514	129.497	127.982	71.268
Case No.1	1480.4	-2.9%	122.52	127.302	127.654	127.548	128.215	124.515	8.404
Case No.2	1477.6	-3.0%	4.756	124.614	128.082	127.562	127.944	127.216	125.621
Case No.3	1463.3	-4.0%	57.971	124.350	125.984	125.762	125.921	124.369	70.563
Case No.4	1475.4	-3.2%	58.338	125.916	126.839	127.027	126.814	125.277	71.129
Case No.5	1477.3	-3.1%	91.824	184.770	96.813	97.087	185.242	94.679	6.492
Case No.6	1472.7	-3.4%	-1.676	82.592	178.231	93.186	93.429	177.939	97.132
Case No.7	1306.9	-14.3%	51.424	111.172	112.440	112.417	112.393	110.883	63.495
Case No.8	1686.3	10.6%	66.511	140.599	142.005	141.888	141.869	140.333	78.147
Case No.9	1441.2	-5.4%	60.975	128.326	117.895	118.978	129.625	128.125	71.081
Case No.10	1438.0	-5.7%	61.017	128.029	129.361	118.603	118.690	127.821	70.735
Case No.11	1466.8	-3.8%	62.027	130.498	121.149	121.154	131.837	130.438	70.394
Case No.12	1466.8	-3.8%	62.023	130.640	131.847	121.129	121.133	129.292	72.392

Table 7. Influence of cases of loading on the pinned-base frame

Load case	Maximum load capacity of the frame (kN)	% of the load capacity of the General case	Maximum load in columns (kN)						
			col.1	col.2	col.3	col.4	col.5	col.6	col.7
General case	1454.1		52.726	123.634	125.088	125.131	125.134	123.655	74.400
Case No.1	1466.6	0.9%	117.349	126.070	126.041	125.983	126.007	123.036	10.807
Case No.2	1438.2	-1.1%	-9.566	120.942	123.860	124.041	123.990	124.099	136.725
Case No.3	1451.3	-0.2%	51.943	123.396	125.062	125.079	125.118	123.585	75.184
Case No.4	1457.1	0.2%	53.338	124.093	125.320	125.378	125.339	123.704	73.849
Case No.5	1459.9	0.4%	86.726	185.196	96.142	96.113	185.109	93.901	10.917
Case No.6	1438.5	-1.1%	-9.714	92.708	182.442	95.050	95.099	182.589	107.169
Case No.7	1285.0	-11.6%	46.180	109.650	111.089	111.133	111.134	109.670	66.762
Case No.8	1668.6	14.8%	60.866	141.512	143.009	143.050	143.039	141.500	84.191
Case No.9	1379.5	-5.1%	52.975	124.177	115.434	115.471	125.688	124.228	74.741
Case No.10	1379.5	-5.1%	52.773	124.297	125.748	115.587	115.587	124.311	75.052
Case No.11	1403.5	-3.5%	53.932	126.286	117.549	117.587	127.770	126.464	76.059
Case No.12	1403.4	-3.5%	53.917	126.392	127.750	117.562	117.559	126.285	76.037

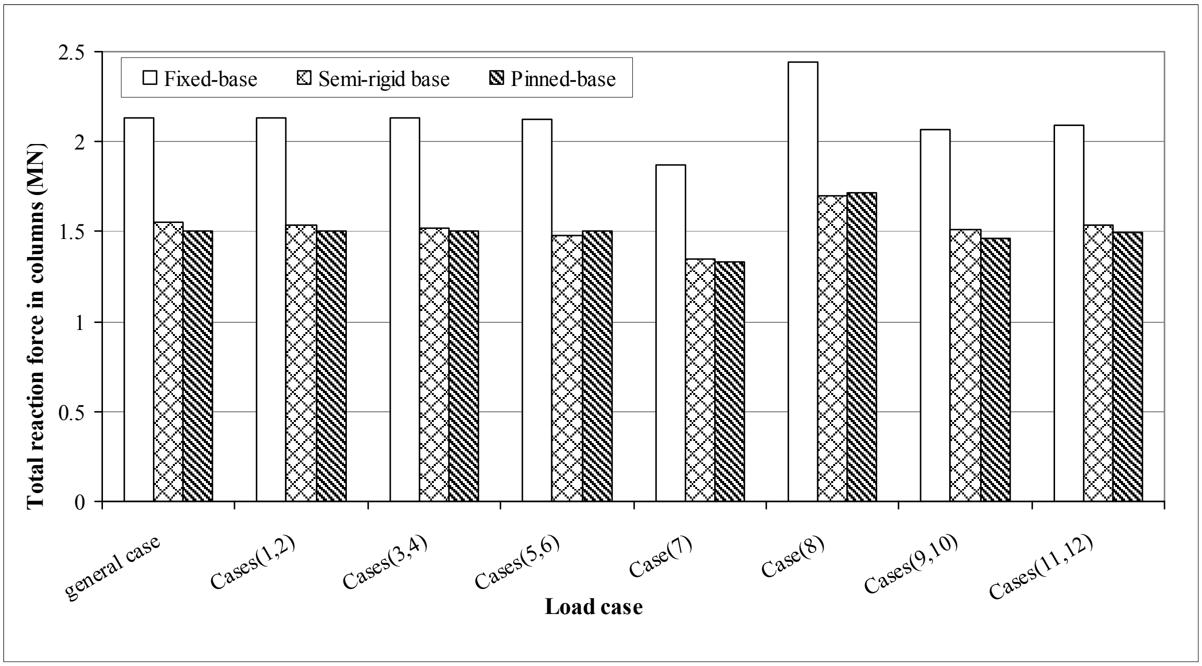


Figure 13. Total reaction in columns for all cases with 1 % (*x*+*z*)-direction)

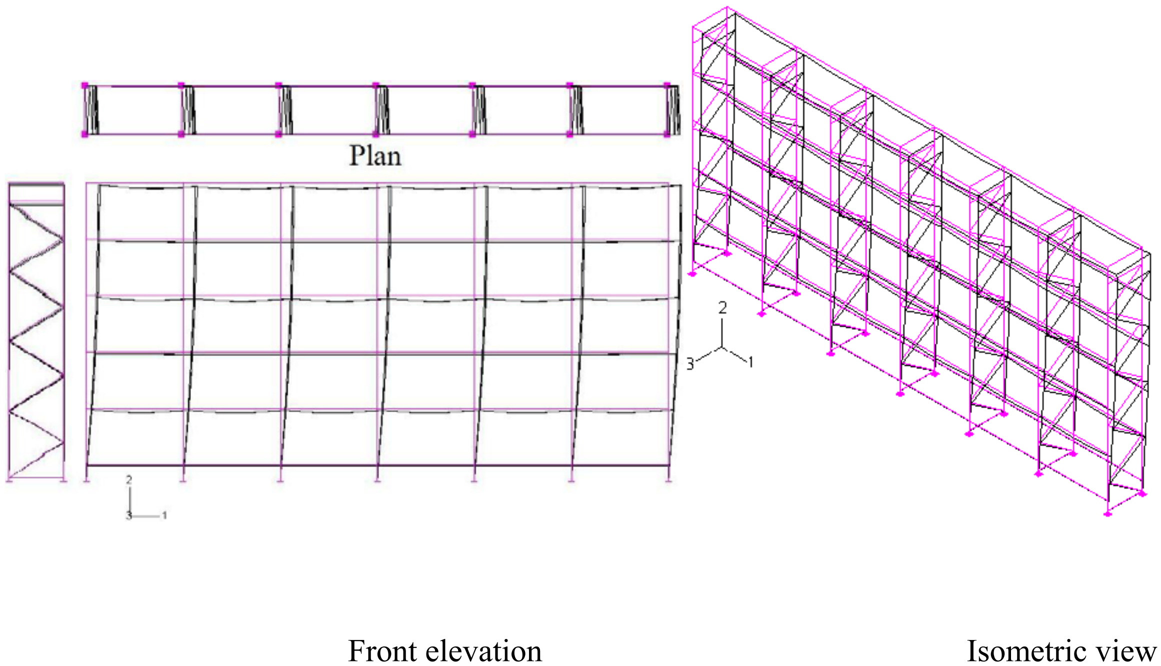


Figure 14. Collapse mode for case 7 (semi-rigid base-plate frame)

Chapter Five

CONCLUSIONS

In the present study, the non-linear static responses of pallet racks with either fixed-bases, semi-rigid bases or pinned-bases with and without initial imperfections have been investigated under different cases of loading. The study found that the frame's behaviour is affected by partial loads and by lateral loads representing initial imperfections.

For the frames without initial imperfections, the study found that for all different type of base fixation the frame reached their maximum load capacity when it's totally fixed. And then, this load capacity is reduce with pinned with semi-rigid and pinned bases up to 55% with reference to the rigid base frame. Moreover when a comparison was carried out between all cases it was found that the most critical type loading occurred when the loads were removed on one bay for all lifts.

For frames with an initial imperfections in down and cross-aisle directions, the study found that for all different type of base fixation the frame reached their maximum load capacity when it's totally fixed and the presence of the initial imperfections in down and cross –aisle directions lead to reduce the difference in load capacity between semi-rigid and pinned base up to 31%. Moreover under a certain combination of presence this imperfection and load cases base-plates fail earlier than rigid and pinned base and when a comparison was carried out between all cases it was found that the most critical type loading occurred when the loads are removed from one level. In all cases of loading the pallet rack structure failed in a global sway mode except the fully loaded case without imperfections.

REFERENCES

Markazi .F.D., Godley M.H.R. and Beale R.G., **"Experimental Analysis of Semi-Rigid Boltless connections"**, Thin Walled Structures, 1997, 27(1), pp53-87.

Beale R.G. and Godley M.H.R. **"Problems arising with pallet rack semi-rigid base-plates"**, Proceedings of the First International Conference on Steel and Composite Structures, Pusan, pp699-706.

Godley M.H.R. **"The behaviour of storage racking baseplates"**, Proceedings of the sixth International Conference on Steel and Aluminium Structures (ICSAS'07), 2007, Oxford, pp433-440.

Godley M.H.R., Beale R.G. and Feng X., **"Analysis and design of down-aisle pallet rack structures"**, Thin-Walled structures, 2000, 77, pp391-401.

A.L.Y. Ng, R.G. Beale and M.H.R. Godley, **"Dynamic collapse of steel rack structures"**, Proceeding of the eight international conference on computational structures technology, 2006.

Baldassino N. and Bernuzzi C., **"Analysis and Behaviour of Steel Storage Pallet Racks"**, Thin-Walled Structures, 2000, 37, pp277-304.

Abdel-Jaber M.S. **"The Influence of Semi-Rigid Connections on the Behaviour of Beam and Column Structural System",** PhD Thesis: Oxford Brookes University, UK, 2002.

Sarawit A.T. and Pekoz T., **"Design of Industrial Storage Racks"**, Proceedings sixteenth International Specialty Conference on Cold-Formed Steel Structures", Orlando, 2002, pp369-384.

Sarawit A.T., **"Cold-Formed Steel Frame and Beam-Column Design"**, PhD Thesis: Cornell University, US, 2003.

Freitas A.M.S., Freitas M.S.R. and Souza F.T., **"Analysis of steel storage rack columns"**, Journal of Constructional Steel Research, 2005, 61(8), pp1135-1146.

Beale R.G., **"The Influence of Semi-Rigid Connections on the Non-Linear Behaviour of Pallet Rack and Scaffold Structures"**. PhD Thesis: Oxford Brookes University, UK, 2004.

Federation Europeéne de la Manutention, Section X, **"Recommendations for the Design of Steel Pallet Racking and Shelving"**, 2000.

The Rack Manufacturers' Institute, **"Specification for the Design, Testing and Utilization of Industrial Steel Storage Racks"**, 1997.

Beale R.G. and Godley M.H.R , "**The Design of the Pallet Program"**, Proceedings of the sixteenth Specialty Conference on Cold-Formed Steel Structures, Orlando, 2002, pp353-368.

Beale R.G. and Godley M.H.R., **"Developments in the pallet program"**, Advances in Structures, Sydney, 2003, pp237-243.

Morz K., Olsson A. and Sandberg G., **"Parameter Studies on Pallet Racks"**, SP Swedish National Testing and Research Institute, SP Report 1998-2, 1998.

Olsson A. and Sandberg G., **"Reduction of load carrying capacity in pallet racks due to damaged upright beams",** Tenth Nordic Seminar on Computational Mechanics, Tallinn, 1997, pp278-281.

Godley M.H.R., **"Plastic Design of Pallet Rack Beams"**, Thin-Walled Structures, 1997, PP175-188.

Beale R.G. and Godley M.H.R , **" Sway analysis of spliced pallet rack structures"**, Thin-Walled Structures, 2004, 82, PP2145-2156.

Bajoria K.M. and Talikoit R.S., **"Determination of flexibility of beam-to-column connectors used in thin walled cold-formed steel pallet racking systems"**, Thin-Walled Structures, 2006, 44, PP372-380

Cabrero J.M. and Bayo E., **"The semi-rigid behaviour of three-dimensional steel beam-to-column joints subjected to proportional loading"**, Journal of Constructional Steel Research, 2007, 63, PP1241-1253.

ABAQUS ANALYSIS User's Manual, Version 6.4, Hibbitt, Karlsson & Sorensen, Inc., 2003.

ABAQUS BENCHMARKS Manual, Version 6.4, Hibbitt, Karlsson & Sorensen, Inc., 2003.

ABAQUS/CAE User's Manual, Version 6.4, Hibbitt, Karlsson & Sorensen, Inc., 2003.

ABAQUS EXAMPLE Problems Manual, Version 6.4, Hibbitt, Karlsson & Sorensen, Inc., 2003.

ABAQUS KEYWORDS Reference Manual, Version 6.4, Hibbitt, Karlsson & Sorensen, Inc., 2003.

ABAQUS THEORY Manual, Version 6.4, Hibbitt, Karlsson & Sorensen, Inc., 2003.

عنوان الرسالة

تأثير حالات التحميل وصلابة صفيحة القاعدة على تصرف رفوف التخزين المعدنية ثلاثية الأبعاد

إعداد

فريال حسين حسن القرعود

المشرف

الدكتور أنيس شطناوي

المشرف المساعد

الدكتور معتصم عبد الجابر

ملخـــــــص

تستخدم رفوف التخزين المعدنية لتخزين السلع في المنشآت الصناعية. في بعض الحالات العملية قد نحتاج الى ازالة بعض هذه السلع من بعض أجزاء منشآت رفوف التخزين. هذه الدراسة تقدم نتائج تأثير حالات التحميل على تصرف منشآت رفوف التخزين المعدنية. تم بناء نموذج رفوف التخزين ثلاثي الأبعاد يتكون من ستة جسور(رفوف) وستة أعمدة (قوائم) وتم اجراء تحليل لا خطي لهذا لهذا المنشئ باستخدام برنامج (ABAQUS).

تم بناء اثنا عشر مجموعات مختلفة من حالات التحميل ، وذلك تحت حالات مختلفة من تثبيت القاعدة وكذلك القوة الأفقية والجانبية. وكنتيجة لهذا التحميل وجد ان معظم الحالات فشلت تحت تأثير الإنبعاج الجانبي. وبالأعتماد على تأثير القوة الجانبية وتثبيت القاعدة وجد أن أكثر حالة حرجة من بين جميع حالات التحميل هي عندما تم تفريغ جسرين متتاليين أو أكثر ووصلت نسبة الأنخفاض في قوة تحمل المنشئ الى 40% من قوة تحمل المنشئ عندما تم تحميلة بشكل كامل.