STUDY ON BEHAVIOR OF REINFORCED BEAM-COLUMN JOINT WHEN SUBJECTED TO SEISMIC LOAD AND THE APPLICATION OF STEEL AS A BRACING

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Study on Behavior of Reinforced Beam-Column Joint when Subjected to Seismic Load and The Application of Steel as a Bracing

By

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DISSERTATION

Submitted to the Civil Engineering Programme
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CERTIFICATION OF APPROVAL

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Approved by,

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

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SITI NORBAYA BINTI CHE NAR

ABSTRACT

This report basically discusses the studies and overview of the chosen topic, which is **Study on Behavior of Reinforced Beam-Column Joint when Subjected to Seismic Load and the Application of Steel as a Bracing**. The situation for building design against earthquake effects in Malaysia is apparently unique. There is no seismic design code as there is no local seismicity, yet the effects of significant regional earthquakes are frequently felt in many high rise buildings in Malaysia. This project is about the application of bracing as a method for strengthening the beam-column joint when subjected to seismic load apart from the gravity loads. The bracing is one of the retrofitting methods in new technology that was brought to embrace the design of reinforced concrete of beam-column joint where it facilitates the strength of the joint. STAADPRO Software is used to assist the calculation of the approximate loads on the reinforced concrete of beam-column joint. Firstly, the building is analyzed and the weakest point of the beam-column joint is determined. At this stage, the chosen steel bracings are proposed and analyzed. The bracings that were used are the Diagonal Bracing and the K-Bracing with different adequate dimensions for each orientation. The parameter that is used as the result to compare is the beam-end displacement in the STAAD.Pro or story drift.

ACKNOWLEDGEMENTS

First and foremost, praised be to Allah, the Most Merciful and the Most Gratitude, for me being able to complete this final year project within the given time.

Secondly, I would like to take this opportunity to give my earnest thanks to Mr. Mohamed Mubarak for his endless patient and idea for this project. For my family who prayed for me, thank you.

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ABBREVIATIONS AND NOMENCLATURES

BS	British Standard
FEA	Finite Element Analysis
ISO	International Standard Organization
NHL	Notional Horizontal Load
UBC	Uniform Building Code
SEAOC	Seismology Committee of the Structural Engineers Association of California

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Components such as beams, columns, connections, shear walls and diaphragms in an existing building may not have adequate strength or deformation capacity, though the building in whole may have substantial strength and stiffness. A higher degree of damage in a building is expected during an earthquake if the seismic resistance of the building is inadequate. The decision to strengthen it before an earthquake occurs depends on the building's seismic resistance. By strengthening the structure, the threshold of the lateral forces at which the damage indicates, can be increased. In this project, the strengthening method that will be proposed is the bracing system made by steel at the beam-column joint.

Recently, earthquake disasters were always been a news line in Asia and the most significant earthquake affected our country; Malaysia was the 2004 Indian Ocean Earthquake. The incident took place on 26 December 2004 where it triggered the big wave of the century, Tsunami 2004. The record stated that the earthquake was 9.0 of magnitude that struck the Indian Ocean off the western coast of northern Sumatra, Indonesia and caused thousands of death. Some affected countries on several areas include Indonesia, Thailand, India, Sri Lanka and also Malaysia.

From that onwards, Malaysia has taken a more serious provision towards building designs in the country where before most of the building structures in Malaysia are designed with less consideration of vibration due to force ground motion. This is because Malaysia is out of the earthquake frequent zone.

The ground movement caused by earthquakes can have several types of damaging effects. Some of the major effects are:

- Ground shaking, i.e back-and-forth motion of the ground caused by the passing waves of vibration through the ground
- Soil failure, such as liquefaction and landslides, caused by shaking;
- Surface fault ruptures, such as cracks, vertical shifts, general settlement of an area, landslides, etc;
- Tidal waves (Tsunamis), i.e. large waves on the surface of bodies of water that can cause major damage to shoreline areas.

1.2 PROBLEM STATEMENT

The research is conducted to study the influence of bracing system using steel as the bracing to the reinforced concrete beam-column joint. Due to the recently tragedy of Tsunami 2004 that triggered by the earthquake and many other earthquake occurrences in the country, the seismic load will be used as the main load to test the behavior of the reinforced concrete apart from the wind load. Nowadays the existing important buildings such as school, hospital and government offices are designed with provision codes concerning the seismic and wind loads.

The subjected building will be tested with the gravity loads and seismic load. The gravity loads consist of dead load and live load. The seismic load is calculated based on Uniform Building Code 1997 (UBC 1997). The joints of the subjected building are tested and the weakest point of the joints is determined within the result of the analysis. At this particular weak joint, steel bracing is proposed. From this, the seismic load will be applied to test the strength of the bracing system.

STAADPRO software will be used as the medium to determine and analyze the effect of the loads on the bracing system.

1.3 OBJECTIVES OF STUDY

The project has the main objectives of:

- To study and analyze the behavior of reinforced beam-column joint concrete when subjected to seismic load calculated in UBC 1997 with usage of STAAD.Pro software.
- To chose the best bracing system for strengthening of the subjected building.

1.4 SCOPE OF STUDY

The scope of study for this project is the analysis of 11-storey residential houses with and without steel bracing. The design in the modeling is only the response in one particular direction. Initially, the properties of the basic structure of the building; beam, column and slab are entered and followed by the loading for the beam and slab. The loadings that will be used consist of two major parts that are Gravity Loads and Seismic Load. Gravity Loads came from the dead load and live load. The seismic load is calculated using portal method, based on the UBC 1997 that was obtained from Building Design and Construction Technology book. The analysis will be run and the weakest joint will be determined from the result obtain. After that, compatible bracing system will be proposed to the weakest joint. The bracing system is divided into two types that are Diagonal Bracing and K-Bracing. Each bracing contains different properties which are Solid Square Steel, Tapered I and Tapered Tube. Again, from these divisions, different dimensions will be chosen according to the application i.e. density, length and width. Comparison between these results will be carried out and comparison between the braced and non-braced building will be obtained. Only the weakest point will be compared in this project referring to the beam-end displacement or here in this report it is known as story drift to give a complete yet satisfying understanding about the relevance of Steel Bracing.

CHAPTER 2

LITERATURE REVIEW

2.1 STEEL BRACING

2.1.1 Definition of Bracing

The idea of using steel as the bracing system came from a long research. Bracing may be added due to load requirements. The most common methods of bracing are diaphragm action, rod or cable bracing, fixed base, or portal frames. Diaphragm action relies solely on the wall & roof panels, when properly installed, to transfer lateral wind and snow loads to the foundation. Rod or cable bracing is the primary alternative to diaphragm action in which rods or cables are attached to the frames between bays to transfer the loads to the foundation. Finally fixed bases or portal frames are used when additional bracing is required, but there is a need for open bays. Also flange bracing is used within the roof system to prevent purlins and mainframes from buckling under heavy loads. See Figure 1.

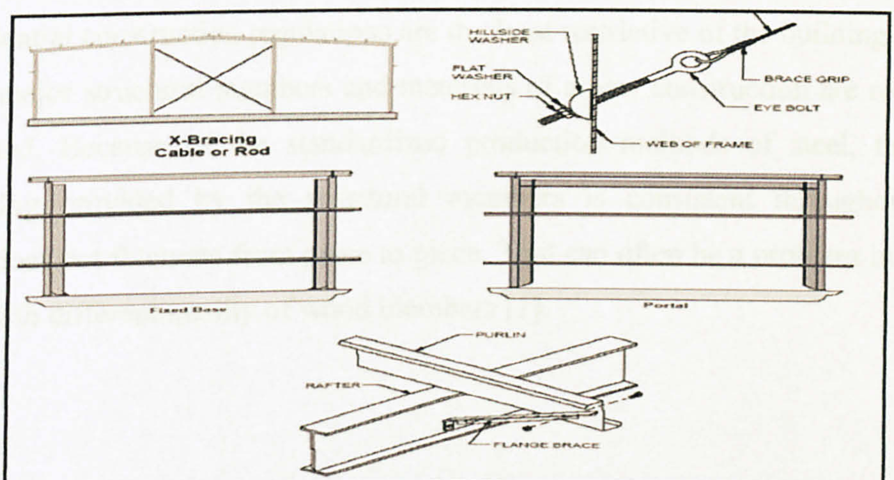


Figure 2.1: Various Bracing

2.1.2 Advantages of Steel Bracing

Steel has the highest strength to weight ratio of any building material, twenty-five times greater than wood. Because of this strength, and the inorganic nature of steel, it does not warp split or twist. Also because the steel member is an inorganic material, it will not swell or shrink in reaction to moisture content. This allows an architect to use true dimensions when designing without the need to compensate for the wood's shrinkage. Additionally, because steel is dimensionally stable and will not "settle" as wood does in new construction dry wall cracks or shifting walls over time including the induced strain put on other structural members is non-existent. The characteristics of steel include a higher ductility than wood, allowing it to bend. In an earthquake, the steel would absorb more of the stresses and be less prone to cracks or breakage. As stated previously, the connections within a steel frame structure are less susceptible to pull out or failure and will not weaken over time because of material shrinkage or the decrease in strength of the base material due to age [1].

The largest fire safety selling point of steel framing in comparison to wood is that the steel framing is non-combustible. It does not burn and will not provide additional fuel to the fire. The structural members will deform and will reach a critical point where eventual failure will occur but they do not provide additional fuel, nor perpetuate the fire growth. Residential construction regulations are the least restrictive of the building codes. However, all major structural members and materials of a new construction are required to be fire rated. Because of the standardized production methods of steel, the fire resistance rating provided by the structural members is consistent throughout the structure and does not fluctuate from piece to piece. That can often be a problem in wood construction with different quality of wood members [1].

2.2 REINFORCED CONCRETE

The observations on the performance of structures during strong earthquakes have served as an age- old means of educating builders on proper and improper construction of earthquake load resisting systems. In regions that have long been inhabited, and that are subjected to relatively frequent strong ground shaking, design procedures have evolved that result in relatively good performance of engineered structures. Although such design procedures are not universally applicable because of regional differences in construction styles, structural engineers can learn much by studying such procedures. The structural engineer can also draw upon a broad data base of engineering observations that have been reported systematically following recent earthquakes [2]. Some of the observations as they apply to design of reinforced concrete structures are highlighted.

The damaging potential of strong earthquakes is well known and is accepted as an underlying premise by most design codes. For example, the Seismology Committee of the Structural Engineers Association of California (SEAOC) adopts the philosophy that structural damage is acceptable during the rare earthquake but that collapse is not acceptable in any event. Thus, an engineer should not be surprised if buildings designed according to the SEAOC recommended lateral force provisions exhibit structural damage following a severe earthquake. However, an observation of performance that suggests the possibility of incipient collapse is certainly noteworthy. From such observations can be gleaned lessons on construction to be avoided.

2.3 SHEAR STRENGTH

Shear strength of beams and columns of a moment resisting frame plays double roles, one in the pre-yield (elastic) range and another in the post-yield (inelastic) range. For members in which yield hinges are not expected to occur, premature shear force associated with the formation of yield mechanism to the shear strength of the member in the elastic range, i.e. shear strength at the pre-yield shear failure, which may be referred to as 'elastic' shear strength. On the other hand, for members in which yield hinges are expected to occur, hinge rotation corresponding to the maximum anticipated deformation must be ensured. According to the recent knowledge of shear strength of the inelastic range, shear strength is not a unique constant but is a decreasing function of the inelastic deformation of yield hinge. By equating the shear force associated with the deformation of yield mechanism to inelastic shear strength, inelastic deformation corresponding to the inelastic shear strength is ensured to occur to the member [3].

2.4 DUCTILITY

One of the basic requirements in reinforced concrete is ductility. Ductility is defined as the capacity of a material, cross section of a structural member, or structure to undergo considerable plastic deformation without loss of strength capacity. Ductility is a measure of the energy absorption capacity. The best way to quantify ductility is through deformation, deflection, or rotation. Recent developments have allowed the production and utilization of high strength concretes to become widespread in the construction industry.

Research has shown that, in certain situations, elements made with high-strength concrete exhibit different failure mechanisms from those found in normal-strength concretes. Therefore, the simple extrapolation to high-strength concretes of models, equations, and procedures valid for normal-strength concretes may lead to unsafe designs [4].

2.5 STIFFNESS AND DRIFT LIMITATIONS [5]

Stiffness is the resistance of an elastic body to deformation by an applied force. It is an extensive material property. In shaking a building, an earthquake ground motion will search for every structural weakness. These weaknesses are usually created by sharp changes in stiffness, strength and/or ductility, and the effects of these weaknesses are accentuated by poor distribution of reactive masses. Severe structural damage suffered by several modern buildings during recent earthquakes illustrates the importance of avoiding sudden changes in lateral stiffness and strength. Inspections of earthquake damage as well as the results of analytical studies have shown that structural systems with a soft story can lead to serious problems during severe earthquake ground shaking.

One simple parameter that affords an estimate of the lateral stiffness of a building is the drift index, defined as the ratio of the maximum deflection at the top of the building to the total height. In addition, the corresponding value for a single story height, the interstory drift index, gives the measure of possible localized excessive deformation. The control of the lateral deflections is of particular importance for modern buildings in which the traditional reserves of stiffness due to heavy internal partitions and outer claddings have largely disappeared. It must be stressed, however, that even if the drift index is kept within traditionally accepted limits, such as 1/500, it does not necessarily follow that the dynamic comfort criteria will also be satisfactory.

Problems may arise, for example, if there is coupling between bending and torsional oscillations that leads to unacceptable complex motion or accelerations. In addition to static deflection calculations, the questions of the dynamic response, involving the lateral acceleration, amplitude, and the period of oscillation may have also to be considered.

The establishment of a drift index limit is major design decisions but unfortunately there are no ambiguous or widely acceptable values, or even in some of the National Codes, any firm guidance. The designer is then faced with having to decide on an appropriate value.

Design drift index that have been used in different countries range from 0.001 to 0.005. a maximum horizontal top deflection of between 0.1 and 0.5m (6 to 20 in.) would be allowed in a 33-story. Generally, lower values should be used for hotels and apartment buildings than for office buildings, since noise and movement tend to be more disturbing for the former. Considering may be given to whether the stiffening effects of any internal partitions, infills, or claddings are included in the deflection calculations.

Sound engineering judgment is required when deciding on the drift index limit ~~is~~ to be imposed. However for conventional structures, the preferred acceptable range is 0.0015 to 0.03 (approximately 1/650 to 1/350), and the sufficient stiffness must be provided to ensure that the top deflection does not exceed this value under extreme load conditions. As the height of the building increases, drift index coefficient should be decreased to the lower end of the range to keep the top story deflection to a suitable low level.

If excessive the drift of a structure can be reduced by changing the geometric configuration to alter the mode of lateral load resistance, increasing the bending stiffness of the horizontal members, adding additional stiffness by inclusion of stiffer wall or bracing system.

2.6 SEISMIC LOADING

For seismic effects due to distant earthquakes, epicentral distance is a major consideration as well as earthquake magnitude. Extreme event scenarios of a magnitude 9 Sumatran subduction earthquake [6]or a magnitude 7.6 earthquake along the Sumatran fault lead [7] to conclusions that elastic base shear demand is likely to exceed the 1.5% NHL provision. Given this, it may be advisable to provide a seismic code or at least design guide for Malaysia. Possible models are due to ISO [8], the Australian code AS1170.4 [9] and the Indonesian code [10], all under review at the time of writing. The last of these is relatively simple and even includes Singapore, but in zone 6 for which zero seismicity is assumed. For zone 5 a base seismic coefficient of 2% of building weight is used and there are consequences on robust design with consideration for seismic effects, for which there is officially no requirement in Malaysia as Malaysia is out of the Fire Zone.

For seismic waves, the initial waves have a longitudinal action and they are called primary or P waves. These waves will eventually induce second waves, S waves. When P and S waves reach the surface they create two other waves, Love and Rayleigh waves. See Figure 2.2.

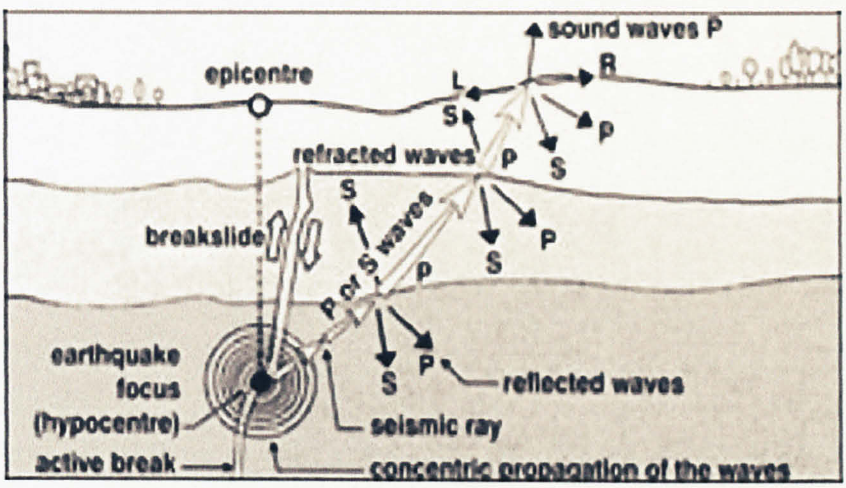


Figure 2.2: Propagation of Seismic Waves [11]

2.7 STAAD.PRO SOFTWARE

STAAD.Pro is chosen as the instrumented software in the project because STAAD.Pro is the most popular structural engineering software product for 3D model generation, analysis and multi-material design. It has an intuitive, user-friendly GUI, visualization tools, powerful analysis and design facilities and seamless integration to several other modeling and design software products. The software is fully compatible with all Windows operating systems but is optimized for Windows XP.

For static or dynamic analysis of bridges, containment structures, embedded structures (tunnels and culverts), pipe racks, steel, concrete, aluminum or timber buildings, transmission towers, stadiums or any other simple or complex structure, STAAD.Pro has been the choice of design professionals around the world for their specific analysis needs.

CHAPTER 3
METHODOLOGY

3.1 INTRODUCTION

As we design a building that is capable of withstanding an earthquake, engineers can choose various structural components, the earthquake resistance of which now well-known understood and then combine them into what is known as a complete lateral load resisting system. These structural components usually include:

- Shear walls
- Braced frames
- Moment resisting frames
- Diaphragms
- Horizontal trusses

Hence, as suggested by the title of the project, it is chosen that the braced system to be analyzed. The most crucial part of this project is the application of steel plate bracing when reinforced beam-column joint is subjected to the seismic load. After getting a general overview of the project, all the relevant information on the topic was searched through the internet and library. The information gathered fell under these categories:

- Steel bracing
- Reinforced concrete
- Seismic loadings
- Description of instrumented structure, STAAD.Pro

The selection of the model has lead to the Proposed Development of Nusajaya Police Headquarters, Johor Bahru, Johor Darul Takzim which is a building of 11-storey quarters for residential purpose. It is a reinforced concrete building and owned by Kementerian Dalam Negeri (Polis DiRaja Malaysia). Firstly, the analysis of the buiding that based from the structural drawing will be performed. From the result, the weakest beam-column joint will be determined and steel bracing with different orientation and various dimensions will be proposed. See Figure 1 for the flow of the project.

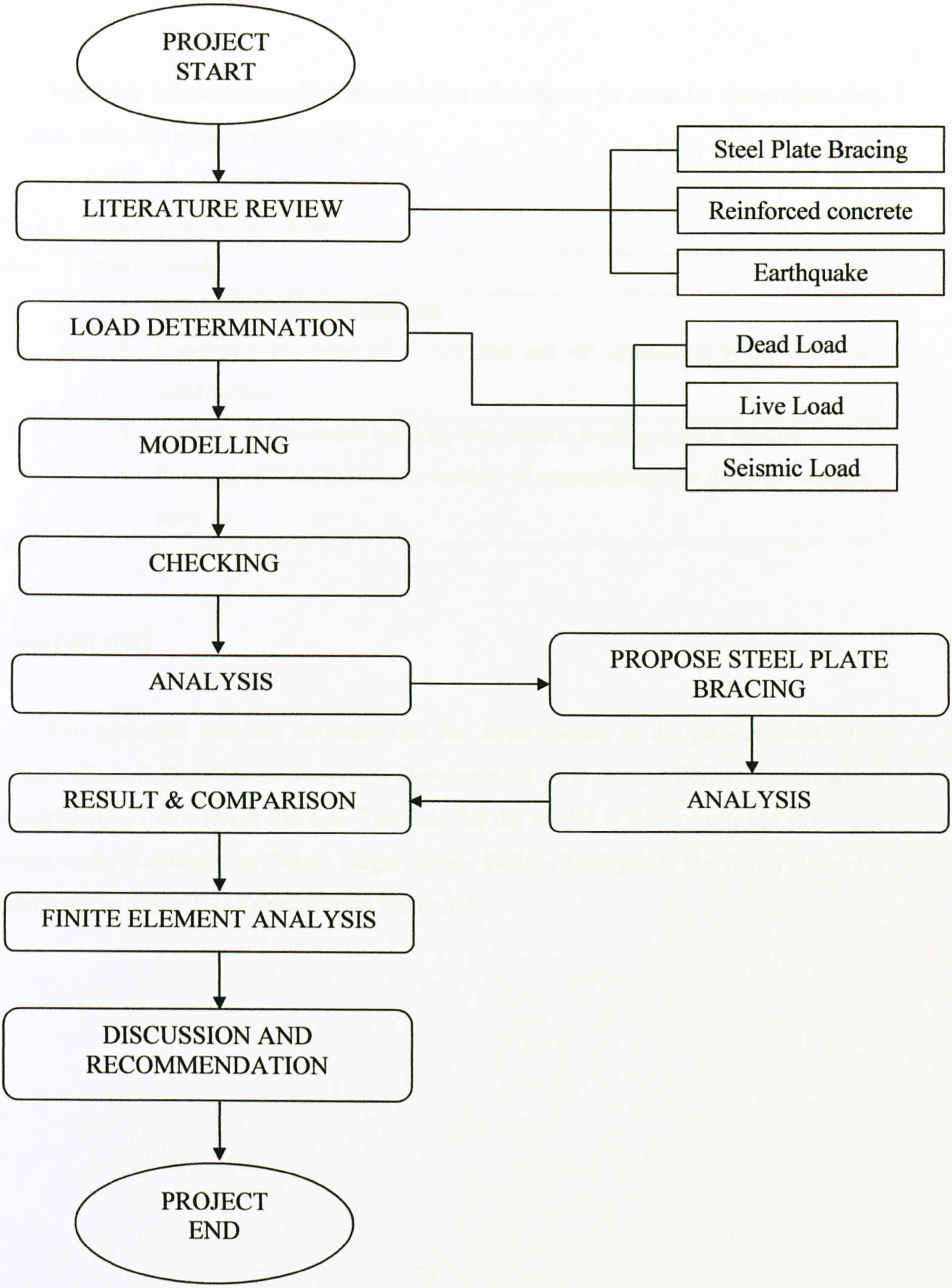


Figure 3.1: Project Flowchart

Table 3.1 below summarizes the division of works to be done for the project. See Appendix A for the project milestone.

Table 3.1: Division of Project Work

Division	Project Work
FYP I	1. Literature review and planning 2. Understand the basic of STAAD.Pro and its' application in the world of construction
FYP II	3. Analysis of the control building with seismic loading as main loading 4. Proposal of Steel Bracing as medium of strengthening for the beam-column joint

3.2 MODELING

The subjected building structure that has been chosen as the project building is 11-storey Class F Quarters for Proposed Development of Nusajaya Police Headquarters in Johor Bahru, Johor Darul Takzim. The data for the model is taken from the structural drawing under Kementerian Dalam Negeri (Polis DiRaja Malaysia). The detail is shown in next page in Table 3.2, Table 3.3 and Table 3.4.

Table 3.2: Building Data

No	Title	Remark
1.	Client	Kementerian Dalam Negeri (Polis DiRaja Malaysia)
2.	Name of Project	Proposed Development of Nusajaya Police Headquarters, Johor Bahru, Johor Darul Takzim
3.	Terrain	Area with no obstruction
4.	Building Purpose	Residential House
5.	Number of Storey	11-Storey
6.	Material	Reinforced Concrete, Steel Bracing
7.	Grade of Concrete	30
8.	Concrete Density	25 kN/m^3
9.	Exposure Condition	Moderate
10.	Fire Resistance	2 hours

Table 3.3: Dimensions of the Building

No.	Title	Dimension
1.	Height of Building	44.0 m
2.	Height of Storey	4.0 m
3.	Width	24.0 m
4.	Length	24.0 m
5.	Slab	150 mm (Thickness for all)

Table 3.4: Dimensions of Members and Concrete Strength

Floor Story	Column	Beam	F_c (N/mm^2)
9-11	0.60 x 0.60	0.60 x 0.45	25
5-8	0.75 x 0.60	0.60 x 0.45	25
1-4	0.85 x 0.60	0.60 x 0.45	25

3.2.1 2-Dimensional and 3-Dimensional Model

2-Dimensional Structure Model is modeled in STAAD.Pro which lies on x and y plane. The example of 2-D Model building is shown in Figure 3.2. Meanwhile 3-Dimensional Structure Model is a modeled in STAAD.Pro which lies on x, y and z plane. The example of 3-D Model building is shown in Figure 3.3.

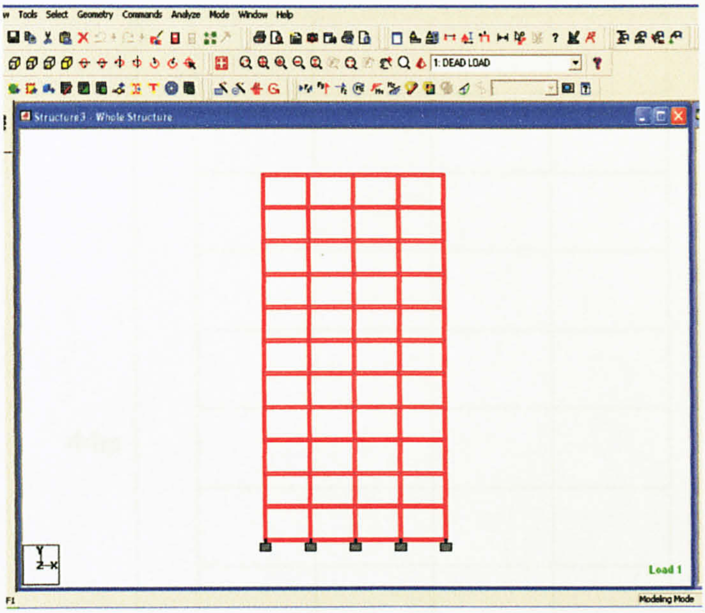


Figure 3.2: 2-Dimensional Structure Model

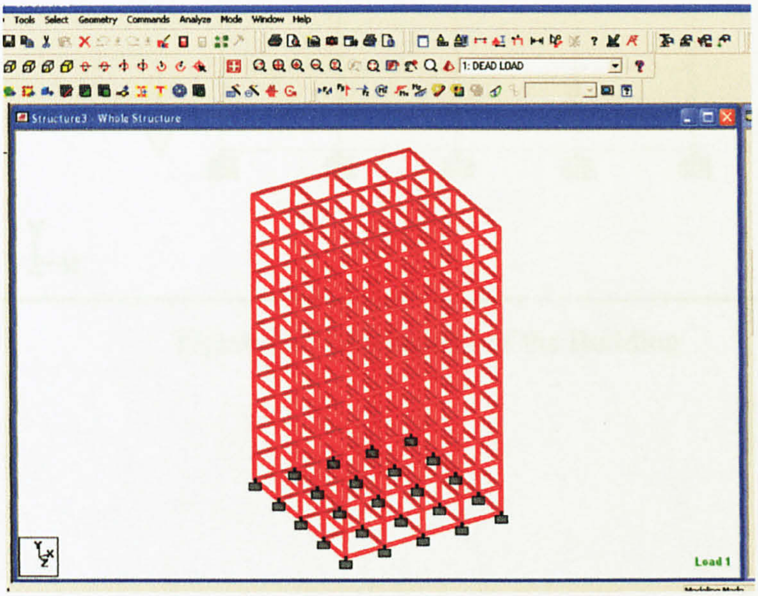


Figure 3.3: 3-Dimensional Structure Model

3.2.2 Dimensions of Building

Figure 3.4 shown below is the dimension of the 11-storey building.

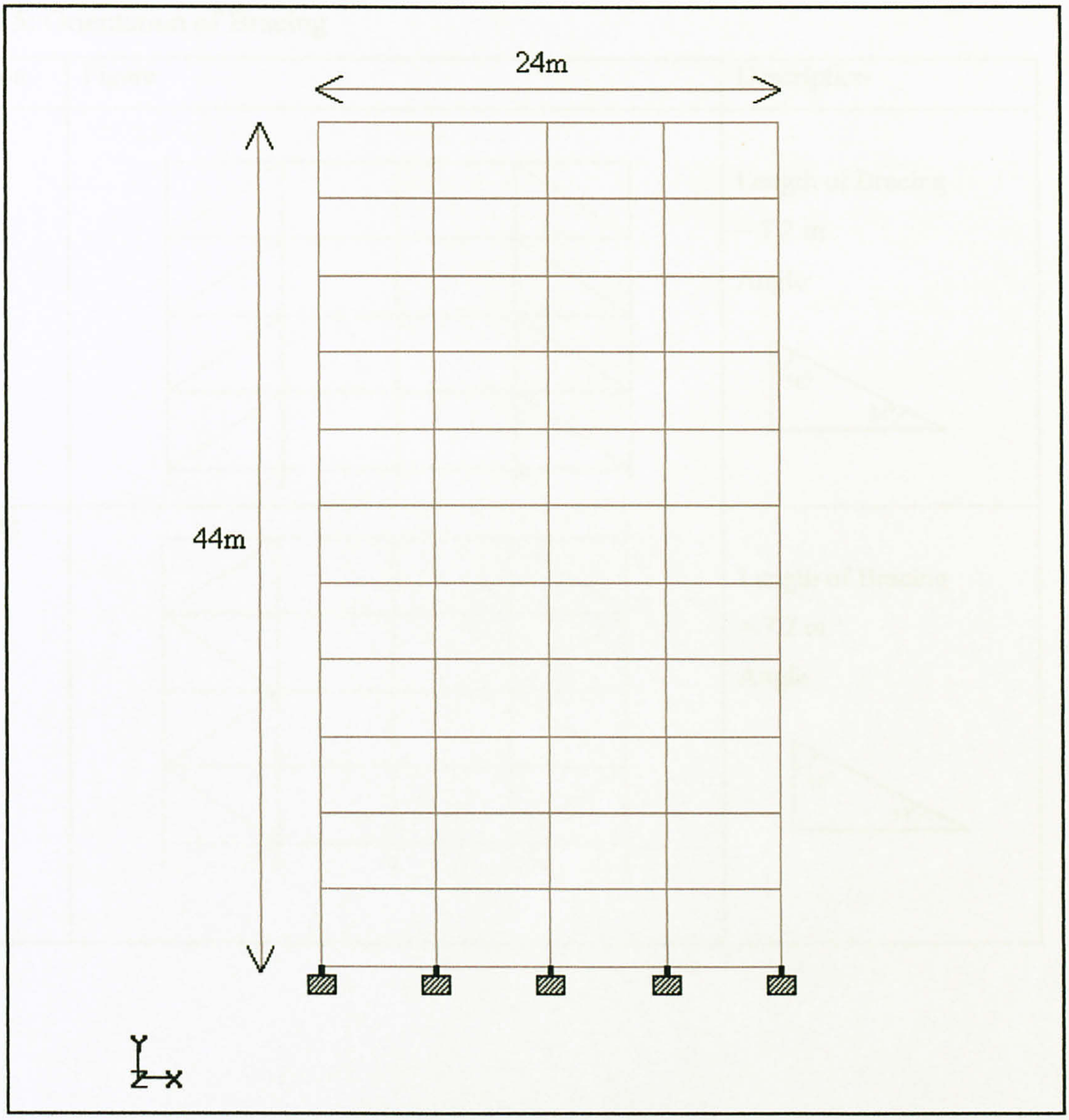
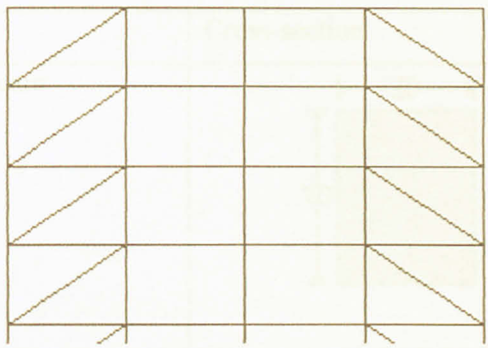
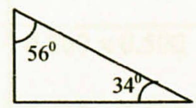
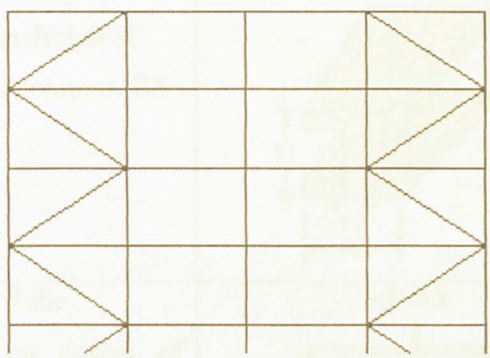
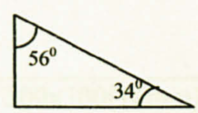


Figure 3.4: Dimensions of the Building

3.2.3 Orientation of Bracing

Table 3.5 shown below is the orientations bracing that were used in this project.

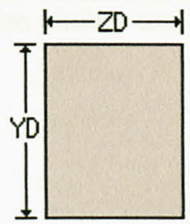
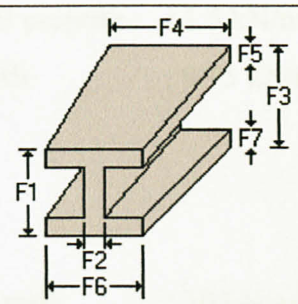
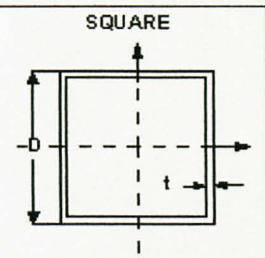
Table 3.5: Orientation of Bracing

Orientation	Figure	Description
Diagonal		Length of Bracing = 7.2 m Angle 
K-Bracing		Length of Bracing = 7.2 m Angle 

3.2.4 Type of Bracing

Table 3.6 shown below is the types and dimensions of bracing that were used in this project. The particular types of bracing are Solid Square, Tapered-I and Tapered-Tube Steel.

Table 3.6: Types and Dimension of Bracing

Orientation	Type	Cross-section	Dimension (mm)
Diagonal & K-Bracing	Solid Square		0.300 x 0.300
			0.400 x 0.400
			0.500 x 0.500
			0.600 x 0.600
	Tapered I *based on design of universal columns, BS 5950		203 x 203 x 86
			305 x 305 x 283
			356 x 406 x 634
	Tapered Tube *based on design of square hollow sections, BS 5950		300x300(16mm)
			350x350(16mm)
			400x400(20mm)

3.3 LOAD DETERMINATION

3.3.1 Gravity Load; Dead Load and Live Load

The first load components that are defined in this project are Live Load, LL and Dead Load, DL. These loads are applied to the slab plates and beams. Both slab and beams have the DL of selfweight which were calculated by STAAD.Pro by the properties of the corresponding slabs and beam. For this project, the thickness of all slabs is same that is 150 mm and the dimension of the beams are the same for all floors that is 600mmx250mm.

Load for Slab:

- Selfweight
- LL, for residential purpose : 1.5 kN/m^2
- DL, for floor finish : 0.75 kN/m^3

Load for Beam:

- Selfweight
- DL, for concrete wall : 10 kN/m^3

3.3.2 Seismic Load

Consequently, the general philosophy of earthquake-resistant design for buildings is based on the principles that they should:

1. Resist minor earthquakes without damage;
2. Resist moderate earthquakes without structural damage but accepting the probability of nonstructural damage;
3. Resist average earthquakes with the probability of structural as well as non structural damage, but without collapse.

The calculation for seismic loading design for this particular building is adopted from the book; "Tall Building Structures; Analysis and Design" by Bryan Stafford and Alex Coull using Portal Method. The UBC states that the building shall be designed to resist minimum total lateral seismic load, base shear V where V is calculated from the formula

$$V = \frac{C_v I W}{RT}$$

in which

$$T = C_t (h_n)^{3/4}$$

Where;

C_t = 0.03 for Reinforced Concrete Moment Frames

C_v = Seismic Coefficient from Table 16-R

h_n = Height of Building

I = Importance Factor from Table 16-K

R = Seismic Over Strength and Ductility from Table 16-N and Table 16-P

T = Building Period given formula above

W = Building Weight

Z = Seismic Zone Factor from Table 16-I

The calculated Base Shear, V is 3297 kN and the Seismic Intensity is equal to 3297 kN divide by 1056 m^2 that is 3.122 kN/m^2. See Appendix C for manual calculation.

3.3.3 Load Combination

This project took British Standard BS8110 as the code of practice for structural use of concrete. From BS8110, the load combination is taken as the following:

a) Load Combination 1: $U= 0.75G_k + 0.75Q_k + 0.75EQ$

Where,

U = Ultimate Load

G_k= Dead Load, DL

Q_k= Live Load, LL

EQ= Earthquake

3.4 DESIGN INFORMATION AND ASSUMPTIONS

In the design of structure, the following Codes of Practice provided the guide:

- BS 8110: Part 1: 1997 – Structural Use of Concrete
- BS 5950-1: 2000 – Code of Practice for Design – Rolled and Welded Sections
- Uniform Building Code, 1997: Wind Load and Earthquake Load Provisions

3.4.1 Concrete

Density	: 25 kN/m^3
Poisson ration	: 0.17
Elasticity	: 22 N/mm^2

3.4.2 Steel

Yield Strength	: 420 N/mm^2
Tensile Strength	: 500 N/mm^2
Elasticity	: 205 000 N/mm^2
Poisson Ratio	: 0.03

3.4.3 Reinforcement

Yield strength of main reinforcement steel, Fymain	: 460 N/mm^2
Yield strength of shear reinforcement steel, Fymain	: 460 N/mm^2
Compressive strength of concrete, Fc	: 25 N/mm^2
Minimum size of main reinforcement, Minmain	: 12 mm
Minimum size of shear reinforcement, Minsec	: 8 mm
Maximum size of main reinforcement, Minmain	: 25 mm

460 N/mm^2 is used for the yield strength of shear reinforcement steel, Fymain rather than 250 N/mm^2 as the slab for this building is 150mm in thickness and this yield strength is compatible with the slab design.

3.4.4 Base support

The base support used for the structure was fixed support.

3.5 CONCEPT OF DISPLACEMENT

In this project, the beam-end-displacement at a particular node or joint will be analysed and compared as a parameter to see the behavior of beam-column joint when subjected to the seismic load. This has come to conclusion where:

The maximum allowable deflection for the structural members due to Uniform Building Code (UBC) 1997 is:

$$\text{Maximum Deflection} = \frac{\text{Length of Structure}}{240}$$

$$= \frac{24000\text{mm}}{240}$$

$$= \mathbf{100mm}$$

Here in this project the displacement in the STAAD.Pro is the same with story drift that will be discussed in Chapter 4 and 5.

CHAPTER 4

RESULTS AND DISCUSSION

In this project there will be two important analysis which are the analysis of the building from the structural drawing and another is the analysis of the building where it will be modified from the first analysis by using the steel brace.

4.1 STORY DRIFT

Table 4.1 shows the result of story drift for each story for the control building without the bracing. At the highest level which is the 11^{th} – storey, the highest story drift takes place with total 263.974mm. This value is higher than the allowable deflection by UBC 1997.

Table 4.1: Control Building Story Drift

Story	Node	Drift (mm)
1	1	0.000
	26	28.771
2	26	28.771
	27	76.286
3	27	76.286
	28	122.128
4	28	122.128
	29	161.310
5	29	161.310
	30	194.043
6	30	194.043
	31	218.540

7	31	218.540
	32	236.112
8	32	236.112
	33	248.276
9	33	248.276
	34	256.810
10	34	256.810
	35	261.4
11	35	261.4
	36	**263.974>100 max**

4.2 MAXIMUM STORY DRIFT

Table 4.2 shows the maximum story drift for the control building without the incorporation of bracing. Table 4.3, 4.4, 4.5 and 4.6 are the building with Solid Square Bracing, Tapered-I Bracing and Tapered-Tube Bracing, respectively. These bracings are tested with different dimensions as discussed in Chapter 3.

Table 4.2: Control Building without Bracing

Orientation	Dimension of Bracing	Beam-Column Joint	Maximum Drift			
			X mm	Y mm	Z mm	Resultant mm
-	-	708- 51/36	263.974	-0.902	0.067	**263.976**

Table 4.3: Building with Steel Bracing (Solid Square) – 7.2m

Orientation	Dimension of Bracing (mm x mm)	Beam-Column Joint	Maximum Drift			
			X mm	Y mm	Z mm	Resultant mm
Diagonal	300 x 300	708-51/36	109.088	-1.386	0.137	109.097
	400 x 400		105.790	-1.854	0.094	105.806
	500 x 500		103.715	-2.437	0.052	103.744
	600 x 600		102.075	-3.128	0.009	102.123
K-Bracing	300 x 300	708-51/36	95.498	-0.518	0.613	**95.500**
	400 x 400		91.539	-0.902	0.112	91.544
	500 x 500		89.160	-1.383	0.068	89.171
	600 x 600		87.316	-1.950	0.028	87.338

Table 4.4: Building with Steel Bracing (Tapered-I) – 7.2m

Orientation	Bracing Designation	Beam-Column Joint	Maximum Drift			
			X mm	Y mm	Z mm	Resultant mm
Diagonal	203 x 203 x 86	708-51/36	143.580	-0.574	0.216	143.582
	305 x 305 x 283		118.019	-0.980	0.181	118.023
	356 x 406 x 634		109.486	-1.333	0.134	109.494
K-Bracing	203 x 203 x 86	708-51/36	136.682	0.276	0.285	136.683
	305 x 305 x 283		106.541	-0.158	0.234	106.542
	356 x 406 x 634		96.168	-0.465	0.164	**98.169**

Table 4.5: Building with Steel Bracing (Tapered-Tube) – 7.2m

Orientation	Bracing Designation	Beam-Column Joint	Maximum Drift			
			X mm	Y mm	Z mm	Resultant mm
Diagonal	300x300(16mm)	708-51/36	130.228	-0.763	0.204	130.230
	350x350(16mm)		126.726	-0.822	0.196	126.729
	400x400(20mm)		120.341	-0.952	0.177	120.345
K-Bracing	300x300(16mm)	708-51/36	121.170	0.074	0.272	121.170
	350x350(16mm)		117.076	0.012	0.262	117.076
	400x400(20mm)		109.492	-0.112	0.235	109.492

4.3 DISCUSSION

Nowadays and recently, it is known that the concept of story drift based design is studied extensively for earthquake resistant of reinforced concrete structure.

From the results above we can see the orientation of K-Bracing has less story drift compared to Diagonal Bracing. The chosen bracing to compare with the control building is K-Bracing of Solid Square Steel with dimensions of 0.3m x 0.3m and K-Bracing of Tapered I with dimensions of 356 x 406 x 604. See Figure 4.1.

K-Bracing of Solid Square Steel with dimensions of 0.3m x 0.3m gave the optimum result which has maximum drift of **95.500mm** and less than the allowable drift of 100.000mm by UBC. The other dimensions in K-Bracing of Solid Square Steel gave less maximum drift than the allowable too. Nonetheless, 0.3m x 0.3m is chosen as this K-Bracing is the smallest dimension and talk about cost, this dimension is the most effective. Graph in Figure 4.1 shown below shows the comparison between the control building and the buildings with subjected bracings as mention earlier.

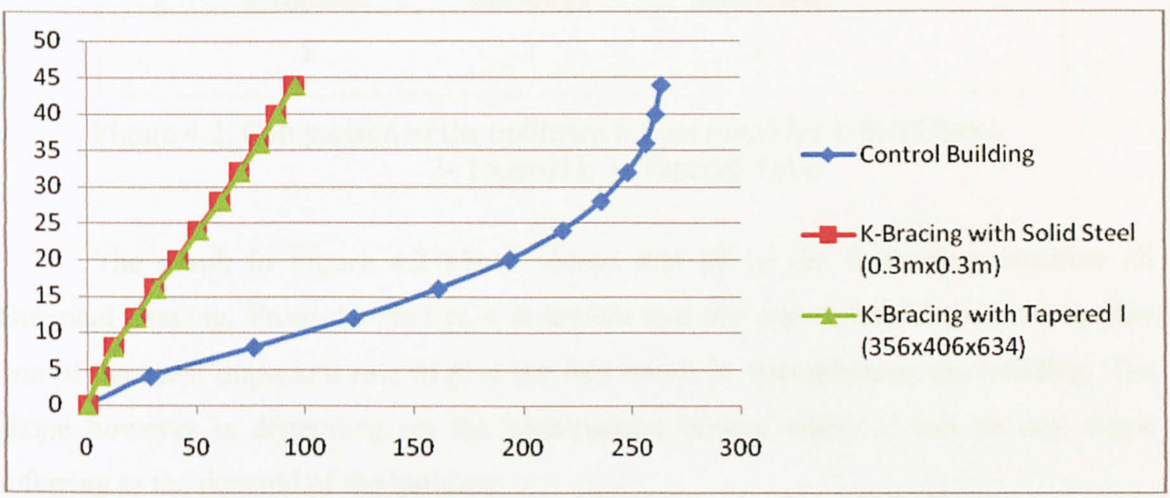


Figure 4.1: Height (m) versus Drift (mm)

For Tapered I type, the orientation of K-Bracing also indicated the lesser maximum drift compared to the Diagonal Bracing. K-Bracing of Tapered I with dimension of 356 x 406 x 634 was the only test subject that passed the allowable drift, that is **98.169mm**.

However, Tapered Tube give higher drift than the allowable drift for each chosen dimension due to the shape that has square hollow at the middle and consequently the shape is inappropriate for bracing system.

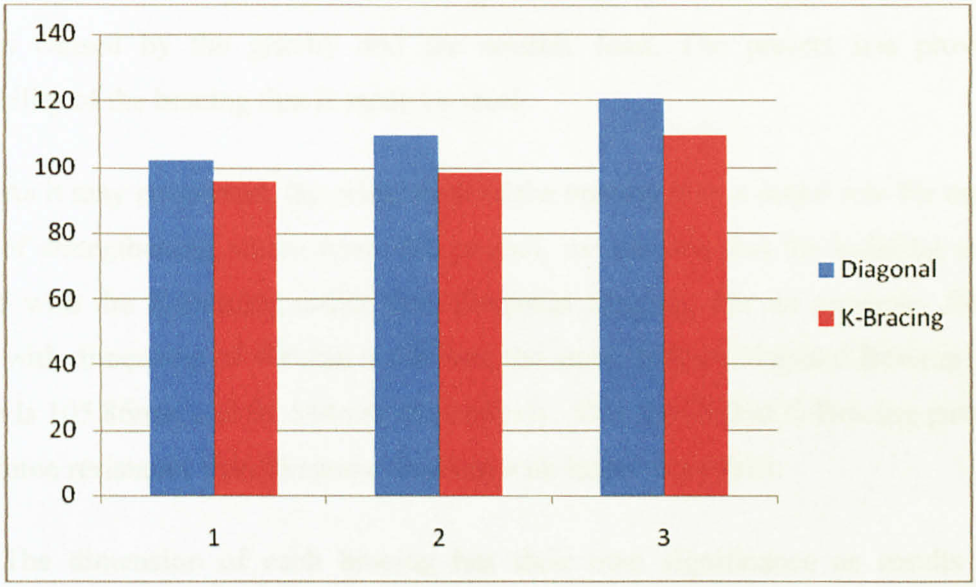


Figure 4.2: Comparison of the optimum results (mm) for 1-Solid Steel, 2- Tapered I, 3- Tapered Tube

The graph in Figure 4.2 above shows that all of the K-Bracing outshine all Diagonal Bracing. From the studies it is known that the orientation of the bracing play one of the most important role to give the best result in strengthening the building. The shape however is depending on the construction budget where it can be any shape referring to the demand of the building.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Bracing is one of the oldest method that is used for strengthening the building structural system. It is proven that bracing takes up the loads applied and resist the damages caused by the gravity and the seismic load. The project has proven the applicability of the bracing that is made by steel.

As it may concerned, the orientation of the bracing play a major role for optimum results of strengthening where from this project, we can see that the building is better oriented with the K-Bracing rather than Diagonal Bracing. For an example, for Solid Square with dimension of 400mm x 400mm, the story drift of Diagonal Bracing and K-Bracing is 105.86mm and 91.544mm respectively. This shows that K-Bracing gave more lateral force resistance than Diagonal Bracing with lesser story drift.

The dimension of each bracing has their own significance as results shown implies that the bigger the dimension, the stronger the bracing. Nevertheless, it is not welcome to use the bigger dimension as the compatible bracing has their own range where smaller dimension would be just adequate for the building rather than using the bigger dimension as it may cost more.

From discussion above, they analysis shows that K-Bracing is a better orientation than the Diagonal Bracing. This is proven by the drift that take place at the end beam of the building. For each type, K-Bracing has lesser drift than Diagonal Bracing. Based on the result of the analysis, Tapered I Steel is the most applicable choice for the selection among all choices of the available tested bracings. This is because Tapered I can withstand the allowable drift and as the optimum result compared to others with lesser cost for manufacturing.

5.2 RECOMMENDATIONS

5.2.1 Usage of other material

Steel is a very advantageous material as the strength is higher compared to the other material. Nonetheless, the cost and the availability of steel at the available market might be a problem in construction management. Thus, it is recommended that the building is tested and applied with other valid material such as reinforced concrete.

5.2.2 Different types of loading

In this project, the seismic load is the main load to be considered. As suggested by the main title, the project can be diversify by using different types of loading i.e. wind loading and snow loading. This would be a good opportunity for a better understanding in bracing system.

5.2.3 Different types of software

Where STAAD.Pro can be very accurate, it is also advisable to use different types of software for the analysis such as EsteemPlus, Orion or ANSYS. ANSYS for example is well known software which has multitasking portfolio for different type of usage. Different types of software may lead to different efficiencies and results.

5.2.4 Exposure to the software usage at early stage

STAAD.Pro is very complicated software which needs a full training, experience and exposure to be able to use and apply in a real job. From this project, it is known that only a little number of persons who are able to major this software. Therefore, there is problem occur where there is a lack of people for a student to go to for a better understanding. For such trouble, students are in serious situation as the project would be delay and incomplete when these kinds of crisis happen. Hence, it is optional that a training session is designed for this kind of purpose so the number of unaware people in the software would be eliminated.

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APPENDICES

APPENDIX A
GANTT CHART

APPENDIX A

GANTT CHART FOR FYP 2 VAB4034 : Study on Behavior of the Reinforced Concrete Beam-Column Joint Using Steel Plate as a Bracing

NO.	DETAIL/WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Design & Analysis Building																	
												R						
2	Proposal of Steel Plate Bracing			I								A						
				L								Y						
3	Analysis of Bracing			I								A						
4	Submission of Progress Report			B					X			B						
				R								R						
5	Poster Presentation			E								E		X				
				A								A						
6	Dissertation Submission			K								K			X			
7	Oral Presentation																	X

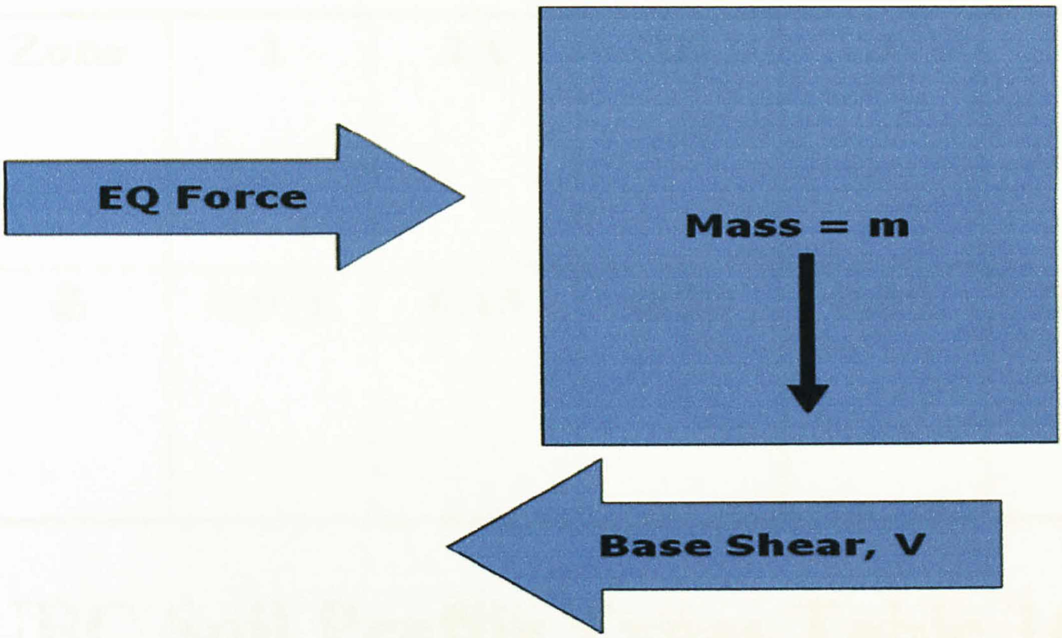
Process Completed

Milestone x

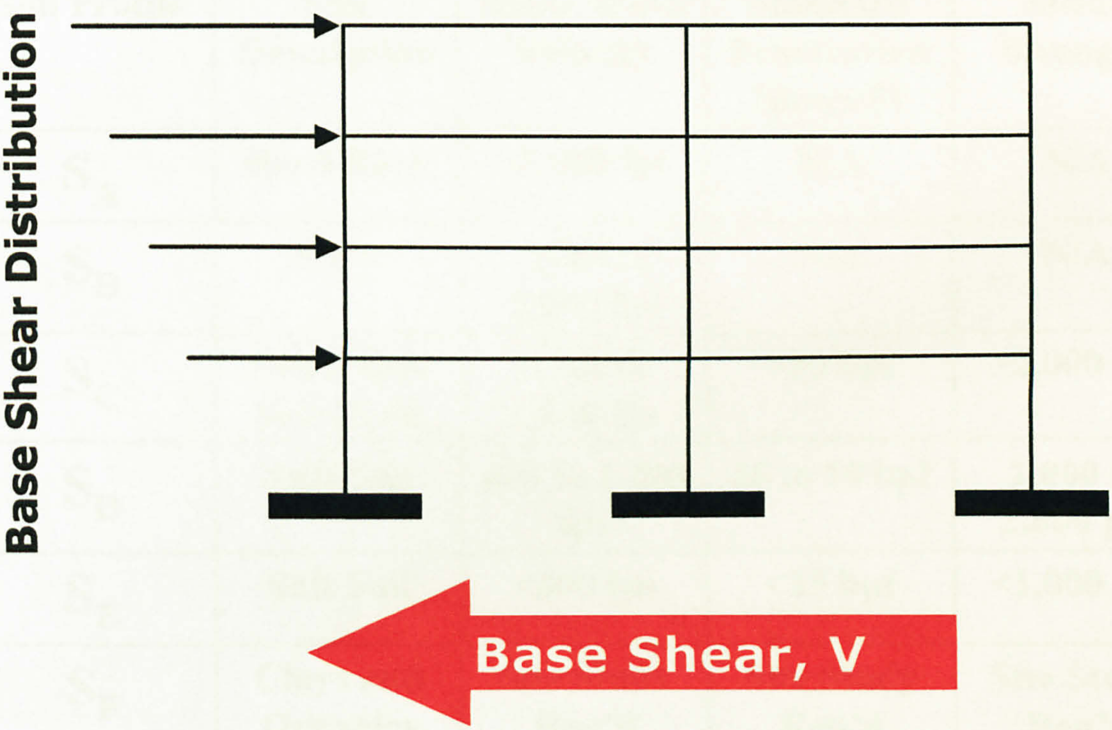
APPENDIX B

UNIFORM BUILDING CODE 1997

UBC 1997



Base Shear Distribution



UBC Table 16-I "Z"

Zone	1	2A	2B	3	4
Z	0.075	0.15	0.20	0.30	0.40

UBC Soil Profile Types Table 16-J

Soil Profile	Soil Description	Shear Wave Velocity	Standard Penetration Blows/Ft	Shear Strength
S_A	Hard Rock	>5,000 fps	N/A	N/A
S_B	Rock	2,500 to 5,000 fps	N/A	N/A
S_C	Dense Soil Soft Rock	1,200 to 2,500 fps	>50 bpf	>2,000 psf
S_D	Stiff Soil	600 to 1,200 fps	15 to 50 bpf	1,000 to 2,000 psf
S_E	Soft Soil	<600 fps	<15 bpf	<1,000 psf
S_F	Clays and Organics	Site Study Req'd	Site Study Req'd	Site Study Req'd

UBC Structural Systems (R) Table 16-N

Structural System	Description	R	Max Height in Zone 3 or 4
Bearing Walls	Shear Panels	5.5	65
	Tension (X) Bracing	2.8	65
Frame System	Steel Eccentric	7.0	240
	Concrete Shear	5.5	240
	Heavy Timber	5.6	65
Moment Frame	Steel	8.5	No Limit
	Concrete	8.5	No Limit
Dual Systems	Masonry/SMRF	5.5	160
	Steel EBF/SMRF	8.5	No Limit

Seismic Coefficient C_a Table 16-Q

Soil Profile	Z = 0.075	Z = 0.15	Z = 0.2	Z = 0.3	Z = 0.4
S_A	0.06	0.12	0.16	0.24	$0.32N_a$
S_B	0.08	0.15	0.20	0.30	$0.40N_a$
S_C	0.09	0.18	0.24	0.33	$0.40N_a$
S_D	0.12	0.22	0.28	0.36	$0.44N_a$
S_E	0.19	0.30	0.34	0.36	$0.36N_a$

Seismic Coefficient C_v Table 16-R

Soil Profile	Z = 0.075	Z = 0.15	Z = 0.2	Z = 0.3	Z = 0.4
S_A	0.06	0.12	0.16	0.24	$0.32N_v$
S_B	0.08	0.15	0.20	0.30	$0.40N_v$
S_C	0.13	0.25	0.32	0.45	$0.56N_v$
S_D	0.18	0.32	0.40	0.54	$0.64N_v$
S_E	0.26	0.50	0.64	0.84	$0.96N_v$

Near Source Factor N_a Table 16-S

	Distance to Known Seismic Source		
Seismic Source Type	≤ 2 km	5 km	≥ 10 km
A	1.5	1.2	1.0
B	1.3	1.0	1.0
C	1.0	1.0	1.0

Near Source Factor N_v Table 16-T

Seismic Source Type	Distance to Known Seismic Source			
	$\leq$ 2 km	5 km	10 km	$\geq$ 15 km
A	2.0	1.6	1.2	1.0
B	1.6	1.2	1.0	1.0
C	1.0	1.0	1.0	1.0

APPENDIX C

MANUAL CALCULATION FOR BASE SHEAR, V

MANUAL CALCULATION FOR BASE SHEAR, V

Design must resist a minimum total lateral seismic load, V:

$$V = \frac{Cv \times I \times W}{RT}$$

- From Table 16-I, the value of Z is 0.15 as the subjected building is located in Zone 2A.
- From Table 16-J, the soil profile is Sc as the soil at the subjected building is dense soil.
- From Table 16-N, the value for R is 5.5 which the building is the Frame System of Concrete Shear.
- From Table 16-R, the value of Cv at Z=0.15 and Sc is 0.25.
- W is the total dead load of the building which is 71 496 kN.

$$\begin{aligned} T &= C_t (h_n)^{3/4} \\ &= 0.03\ (44)^{3/4} \\ &= 0.5125 \end{aligned}$$

- Ct is equal to 0.03 for Frame System of Concrete Shear
- h_n is the total height of the building which is 44m.

Hence,

$$\begin{aligned} V &= \frac{Cv \times I \times W}{RT} \\ &= \frac{0.25 \times 1 \times 71\ 496\text{kN}}{5.5 \times 0.5125} \\ &= 3\ 297\ \text{kN} \end{aligned}$$

Intensity of the Seismic Load = V/A

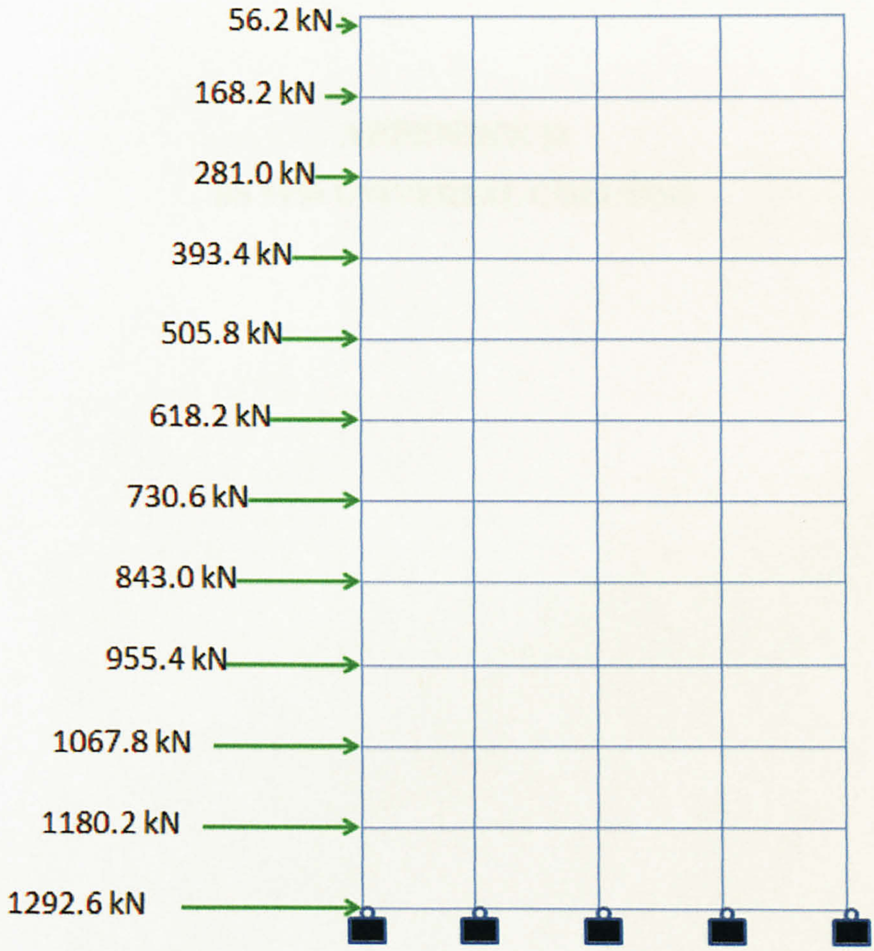
$= \frac{3\ 297kN}{(44 \times 24)m^2}$

$= 3.122\ kN/m^2$

Seismic Load per Floor; Typical Level = $3.122\ kN/m^2 \times 6m \times 6m = 112.4\ kN$

Roof Level = $3.122\ kN/m^2 \times 6m/2 \times 6m = 56.2\ kN$

Seismic Load Distribution Using UBC 1997 (Nodal Load Distribution by portal Method [5]



APPENDIX D

BS 5950 UNIVERSAL COLUMNS

3.1.3 Other properties

For the elastic properties of steel, the following values should be used.

— Modulus of elasticity: $E = 205\ 000$ N/mm²

— Shear modulus: $G = E/[2(1 + \nu)]$

— Poisson's ratio: $\nu = 0.30$

— Coefficient of linear thermal expansion (in the ambient temperature range): $\alpha = 12 \times 10^{-6}$ per 篊

3.2 Bolts and welds

3.2.1 Bolts, nuts and washers

Assemblies of bolts, nuts and washers should correspond to one of the matching combinations specified in BS 5950-2. Holding-down bolt assemblies should conform to BS 7419.

3.2.2 Friction grip fasteners

Friction grip fasteners should generally be preloaded HSFG bolts, with associated nuts and washers, conforming to BS 4395-1 or BS 4395-2. Direct tension indicators conforming to BS 7644 may be used.

Other types of friction grip fasteners may also be used provided that they can be reliably tightened to at least the minimum shank tensions specified in BS 4604.

3.2.3 Welding consumables

All welding consumables, including covered electrodes, wires, filler rods, flux and shielding gases, should conform to the relevant standard specified in BS 5950-2.

The yield strength Y_e, tensile strength U_e and minimum elongation of a weld should be taken as equal to respectively the minimum yield strength R_{eL} or $R_{p0.2}$ (depending on the relevant product standard), tensile strength R_m and minimum percentage elongation on a five diameter gauge length according to the appropriate product standard, all as listed for standard classes 35, 42 and 50 in Table 10.

Table 10 — Strength and elongation of welds

Class	Yield strength Y_e (N/mm²)	Tensile strength U_e (N/mm²)	Minimum elongation (%)
35	355	440	22
42	420	500	20
50	500	560	18

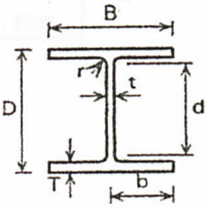
3.3 Steel castings and forgings

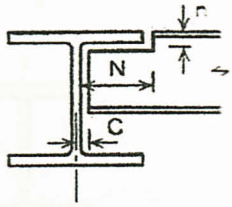
Steel castings and forgings may be used for components in bearings, junctions and other similar parts. Castings should conform to BS 3100 and forgings should conform to BS EN 10250-2. Unless better information is available, design strengths corresponding to structural steel grade S 275 may be adopted.

NOTE Guidance on steel castings is given in reference [4], see Bibliography.

BS 5950-1: 2000
BS 4-1: 1993

UNIVERSAL COLUMNS





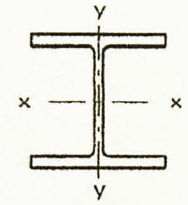
DIMENSIONS

Section Designation	Mass per Metre	Depth of Section D	Width of Section B	Thickness Web t	Thickness Flange T	Root Radius r	Depth between Fillets d	Ratios for Local Buckling Flange b/T	Ratios for Local Buckling Web d/t	Dimensions for Detailing End Clearance C	Dimensions for Detailing Notch N	Dimensions for Detailing Notch n	Surface Area Per Metre	Surface Area Per Tonne
	kg/m	mm	mm	mm	mm	mm	mm			mm	mm	mm	m²	[illegible]
356x406x634 #	633.9	474.6	424.0	47.6	77.0	15.2	290.2	2.75	6.10	26	200	94	2.52	[illegible]
356x406x551 #	551.0	455.6	418.5	42.1	67.5	15.2	290.2	3.10	6.89	23	200	84	2.47	[illegible]
356x406x467 #	467.0	436.6	412.2	35.8	58.0	15.2	290.2	3.55	8.11	20	200	74	2.42	[illegible]
356x406x393 #	393.0	419.0	407.0	30.6	49.2	15.2	290.2	4.14	9.48	17	200	66	2.38	[illegible]
356x406x340 #	339.9	406.4	403.0	26.6	42.9	15.2	290.2	4.70	10.9	15	200	60	2.35	[illegible]
356x406x287 #	287.1	393.6	399.0	22.6	36.5	15.2	290.2	5.47	12.8	13	200	52	2.31	[illegible]
356x406x235 #	235.1	381.0	394.8	18.4	30.2	15.2	290.2	6.54	15.8	11	200	46	2.28	[illegible]
356x368x202 #	201.9	374.6	374.7	16.5	27.0	15.2	290.2	6.94	17.6	10	190	44	2.19	[illegible]
356x368x177 #	177.0	368.2	372.6	14.4	23.8	15.2	290.2	7.83	20.2	9	190	40	2.17	[illegible]
356x368x153 #	152.9	362.0	370.5	12.3	20.7	15.2	290.2	8.95	23.6	8	190	36	2.16	[illegible]
356x368x129 #	129.0	355.6	368.6	10.4	17.5	15.2	290.2	10.50	27.9	7	190	34	2.14	[illegible]
305x305x283	282.9	365.3	322.2	26.8	44.1	15.2	246.7	3.65	9.21	15	158	60	1.94	[illegible]
305x305x240	240.0	352.5	318.4	23.0	37.7	15.2	246.7	4.22	10.7	14	158	54	1.91	[illegible]
305x305x198	198.1	339.9	314.5	19.1	31.4	15.2	246.7	5.01	12.9	12	158	48	1.87	[illegible]
305x305x158	158.1	327.1	311.2	15.8	25.0	15.2	246.7	6.22	15.6	10	158	42	1.84	[illegible]
305x305x137	136.9	320.5	309.2	13.8	21.7	15.2	246.7	7.12	17.9	9	158	38	1.82	[illegible]
305x305x118	117.9	314.5	307.4	12.0	18.7	15.2	246.7	8.22	20.6	8	158	34	1.81	[illegible]
305x305x97	96.9	307.9	305.3	9.9	15.4	15.2	246.7	9.91	24.9	7	158	32	1.79	[illegible]
254x254x167	167.1	289.1	265.2	19.2	31.7	12.7	200.3	4.18	10.4	12	134	46	1.58	[illegible]
254x254x132	132.0	276.3	261.3	15.3	25.3	12.7	200.3	5.16	13.1	10	134	38	1.55	[illegible]
254x254x107	107.1	266.7	258.8	12.8	20.5	12.7	200.3	6.31	15.6	8	134	34	1.52	[illegible]
254x254x89	88.9	260.3	256.3	10.3	17.3	12.7	200.3	7.41	19.4	7	134	30	1.50	[illegible]
254x254x73	73.1	254.1	254.6	8.6	14.2	12.7	200.3	8.96	23.3	6	134	28	1.49	[illegible]
203x203x86	86.1	222.2	209.1	12.7	20.5	10.2	160.8	5.10	12.7	8	110	32	1.24	[illegible]
203x203x71	71.0	215.8	206.4	10.0	17.3	10.2	160.8	5.97	16.1	7	110	28	1.22	[illegible]
203x203x60	60.0	209.6	205.8	9.4	14.2	10.2	160.8	7.25	17.1	7	110	26	1.21	[illegible]
203x203x52	52.0	206.2	204.3	7.9	12.5	10.2	160.8	8.17	20.4	6	110	24	1.20	[illegible]
203x203x46	46.1	203.2	203.6	7.2	11.0	10.2	160.8	9.25	22.3	6	110	22	1.19	[illegible]
152x152x37	37.0	161.8	154.4	8.0	11.5	7.6	123.6	6.71	15.5	6	84	20	0.912	[illegible]
152x152x30	30.0	157.6	152.9	6.5	9.4	7.6	123.6	8.13	19.0	5	84	18	0.901	[illegible]
152x152x23	23.0	152.4	152.2	5.8	6.8	7.6	123.6	11.2	21.3	5	84	16	0.889	[illegible]

Check availability.

FOR EXPLANATION OF TABLES SEE NOTE 2

UNIVERSAL COLUMNS



PROPERTIES

Section Designation	Second Moment of Area		Radius of Gyration		Elastic Modulus		Plastic Modulus		Buckling Parameter	Torsional Index	Warping Constant	Torsional Constant	Area of Section
	Axis x-x	Axis y-y	Axis x-x	Axis y-y	Axis x-x	Axis y-y	Axis x-x	Axis y-y	u	x	H	J	A
	cm^4	cm^4	cm	cm	cm^3	cm^3	cm^3	cm^3			dm^6	cm^4	cm^2
356x406x634 #	275000	98100	18.4	11.0	11600	4630	14200	7110	0.843	5.46	38.8	13700	808
356x406x551 #	227000	82700	18.0	10.9	9960	3950	12100	6060	0.841	6.05	31.1	9240	702
356x406x467 #	183000	67800	17.5	10.7	8380	3290	10000	5030	0.839	6.86	24.3	5810	595
356x406x393 #	147000	55400	17.1	10.5	7000	2720	8220	4150	0.837	7.87	18.9	3550	501
356x406x340 #	123000	46900	16.8	10.4	6030	2330	7000	3540	0.836	8.84	15.5	2340	433
356x406x287 #	99900	38700	16.5	10.3	5080	1940	5810	2950	0.834	10.2	12.3	1440	366
356x406x235 #	79100	31000	16.3	10.2	4150	1570	4690	2380	0.835	12.0	9.54	812	299
356x368x202 #	66300	23700	16.1	9.60	3540	1260	3970	1920	0.844	13.4	7.16	558	257
356x368x177 #	57100	20500	15.9	9.54	3100	1100	3460	1670	0.843	15.0	6.09	381	226
356x368x153 #	48600	17600	15.8	9.49	2680	948	2970	1440	0.844	17.0	5.11	251	195
356x368x129 #	40300	14600	15.6	9.43	2260	793	2480	1200	0.845	19.8	4.18	153	164
305x305x283	78900	24600	14.8	8.27	4320	1530	5110	2340	0.856	7.65	6.35	2030	360
305x305x240	64200	20300	14.5	8.15	3640	1280	4250	1950	0.854	8.74	5.03	1270	306
305x305x198	50900	16300	14.2	8.04	3000	1040	3440	1580	0.854	10.2	3.88	734	252
305x305x158	38800	12600	13.9	7.90	2370	808	2680	1230	0.852	12.5	2.87	378	201
305x305x137	32800	10700	13.7	7.83	2050	692	2300	1050	0.852	14.1	2.39	249	174
305x305x118	27700	9060	13.6	7.77	1760	589	1960	895	0.851	16.2	1.98	161	150
305x305x97	22300	7310	13.4	7.69	1450	479	1590	726	0.852	19.2	1.56	91.2	123
254x254x167	30000	9870	11.9	6.81	2080	744	2420	1140	0.851	8.50	1.63	626	213
254x254x132	22500	7530	11.6	6.69	1630	576	1870	878	0.850	10.3	1.19	319	168
254x254x107	17500	5930	11.3	6.59	1310	458	1480	697	0.849	12.4	0.898	172	136
254x254x89	14300	4860	11.2	6.55	1100	379	1220	575	0.851	14.5	0.717	102	113
254x254x73	11400	3910	11.1	6.48	898	307	992	465	0.849	17.3	0.562	57.6	93.1
203x203x86	9450	3130	9.28	5.34	850	299	977	456	0.849	10.2	0.318	137	110
203x203x71	7620	2540	9.18	5.30	706	246	799	374	0.853	11.9	0.250	80.2	90.4
203x203x60	6130	2070	8.96	5.20	584	201	656	305	0.846	14.1	0.197	47.2	76.4
203x203x52	5260	1780	8.91	5.18	510	174	567	264	0.848	15.8	0.167	31.8	66.3
203x203x46	4570	1550	8.82	5.13	450	152	497	231	0.846	17.7	0.143	22.2	58.7
152x152x37	2210	706	6.85	3.87	273	91.5	309	140	0.849	13.3	0.0399	19.2	47.1
152x152x30	1750	560	6.76	3.83	222	73.3	248	112	0.849	16.0	0.0308	10.5	38.3
152x152x23	1250	400	6.54	3.70	164	52.6	182	80.2	0.840	20.7	0.0212	4.63	29.2

Check availability.

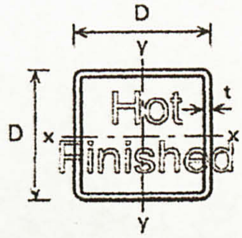
FOR EXPLANATION OF TABLES SEE NOTE 3

APPENDIX E

BS 5950 SQUARE HOLLOW SECTIONS

BS 5950-1: 2000
BS EN 10210-2: 1997

HOT-FINISHED
SQUARE HOLLOW SECTIONS



DIMENSIONS AND PROPERTIES

Section Designation		Mass per	Area of	Ratio for	Second Moment	Radius of	Elastic Modulus	Plastic Modulus	Torsional Constants		Surface Area	
Size	Thickness	Metre	Section	Local Buckling	of Area	Gyration					Per Metre	Per Tonne
D x D	t		A	d/t (1)	I	r	Z	S	J	C		
mm	mm	kg/m	cm^2		cm^4	cm	cm^3	cm^3	cm^4	cm^3	m^2	m^2
140x140	5.0 ~	21.0	26.7	25.0	807	5.50	115	135	1250	170	0.547	26.0
	6.3 ~	26.1	33.3	19.2	984	5.44	141	166	1540	206	0.544	20.8
	8.0 ~	32.6	41.6	14.5	1200	5.36	171	204	1890	249	0.539	16.5
	10.0 ~	40.0	50.9	11.0	1420	5.27	202	246	2270	294	0.534	13.4
	12.5 ~	48.7	62.1	8.20	1650	5.16	236	293	2700	342	0.528	10.8
150x150	5.0 ~	22.6	28.7	27.0	1000	5.90	134	156	1550	197	0.587	26.0
	6.3	28.1	35.8	20.8	1220	5.85	163	192	1910	240	0.584	20.8
	8.0 ~	35.1	44.8	15.8	1490	5.77	199	237	2350	291	0.579	16.5
	10.0	43.1	54.9	12.0	1770	5.68	236	286	2830	344	0.574	13.3
	12.5 ~	52.7	67.1	9.00	2080	5.57	277	342	3370	402	0.568	10.8
	16.0 ~	65.2	83.0	6.38	2430	5.41	324	411	4030	467	0.559	8.57
160x160	5.0 ~	24.1	30.7	29.0	1230	6.31	153	178	1890	226	0.627	26.0
	6.3 ~	30.1	38.3	22.4	1500	6.26	187	220	2330	275	0.624	20.7
	8.0 ~	37.6	48.0	17.0	1830	6.18	229	272	2880	335	0.619	16.5
	10.0 ~	46.3	58.9	13.0	2190	6.09	273	329	3480	398	0.614	13.3
	12.5 ~	56.6	72.1	9.80	2580	5.98	322	395	4160	467	0.606	10.7
180x180	6.3 ~	34.0	43.3	25.6	2170	7.07	241	281	3350	355	0.704	20.7
	8.0 ~	42.7	54.4	19.5	2660	7.00	296	349	4150	434	0.699	16.4
	10.0 ~	52.5	66.9	15.0	3190	6.91	355	424	5050	518	0.694	13.2
	12.5 ~	64.4	82.1	11.4	3790	6.80	421	511	6070	613	0.688	10.7
	16.0 ~	80.2	102	8.25	4500	6.64	500	621	7340	724	0.679	8.47
200x200	5.0 ~	30.4	38.7	37.0	2450	7.95	245	283	3760	362	0.787	25.9
	6.3 ~	38.0	48.4	28.7	3010	7.89	301	350	4650	444	0.784	20.6
	8.0 ~	47.7	60.8	22.0	3710	7.81	371	436	5780	545	0.779	16.3
	10.0	58.8	74.9	17.0	4470	7.72	447	531	7030	655	0.774	13.2
	12.5 ~	72.3	92.1	13.0	5340	7.61	534	643	8490	778	0.768	10.6
	16.0 ~	90.3	115	9.50	6390	7.46	639	785	10300	927	0.759	8.41
250x250	6.3 ~	47.9	61.0	36.7	6010	9.93	481	556	9240	712	0.984	20.5
	8.0 ~	60.3	76.8	28.3	7460	9.86	596	694	11500	880	0.979	16.2
	10.0 ~	74.5	94.9	22.0	9060	9.77	724	851	14100	1070	0.974	13.1
	12.5 ~	91.9	117	17.0	10900	9.66	873	1040	17200	1280	0.968	10.5
	16.0 ~	115	147	12.6	13300	9.50	1060	1280	21100	1550	0.959	8.31
300x300	6.3 ~	57.8	73.6	44.6	10500	12.0	703	809	16100	1040	1.18	20.4
	8.0 ~	72.8	92.8	34.5	13100	11.9	875	1010	20200	1290	1.18	16.2
	10.0 ~	90.2	115	27.0	16000	11.8	1070	1250	24800	1580	1.17	13.0
	12.5 ~	112	142	21.0	19400	11.7	1300	1530	30300	1900	1.17	10.5
	16.0 ~	141	179	15.8	23900	11.5	1590	1900	37600	2330	1.16	8.26
350x350	8.0 ~	85.4	109	40.8	21100	13.9	1210	1390	32400	1790	1.38	16.2
	10.0 ~	106	135	32.0	25900	13.9	1480	1720	39900	2190	1.37	12.9
	12.5 ~	131	167	25.0	31500	13.7	1800	2110	48900	2650	1.37	10.5
	16.0 ~	166	211	18.9	38900	13.6	2230	2630	61000	3260	1.36	8.19
400x400	10.0 ~	122	155	37.0	39100	15.9	1960	2260	60100	2900	1.57	12.9
	12.5	151	192	29.0	47800	15.8	2390	2780	73900	3530	1.57	10.4
	16.0 ~	191	243	22.0	59300	15.6	2970	3480	92400	4360	1.56	8.17
	20.0 ~	235	300	17.0	71500	15.4	3580	4250	113000	5240	1.55	6.60

~ Check availability in S275.

(1) For local buckling calculation d = D - 3t.

FOR EXPLANATION OF TABLES SEE NOTES 2 AND 3