National University of Science and Technology

STATIC AND DYNAMIC ANALYSIS DUE TO EXPLOSION LOADS ON PIPE RACK

Name: Syed Faisal Ahsan

Regn #:2011-NUST-MS PhD-Mech(N)-16

ACKNOWLEDGEMENT

I thank 'Allah', the almighty to have blessed me with energy and support towards the purpose of my life. I thank my parents for their affection and love, which drives me.

The study could not have been accomplished without the guidelines provided by my thesis supervisor Dr. Sohaib Zia Khan and my GEC members.

I would like to thank my university 'National University Of Science and Technology-PNEC(Karachi)' for providing all the facilities library, e-journal management etc., required to complete my work. The environment has been very supportive and encouraging.

ABSTRACT

Any blast on a plant is the result of major accident which together creates a chain reaction leading up to the final explosion. Any accidental release of a gas or liquid will create a fire. However if the gas or liquid releases on a pipe rack, it may lead to formation of a combustible fuel-air cloud, which after ignition will create a hydrocarbon explosion. Further the emergency shutdown of any pipe on the pipe rack when the valves are resting on the rack is not possible on a small amount of time due to the limiting amount of ladders and also the huge length of pipe rack. In many process plants operators room and other buildings such as chillers, compressors are also placed adjacent to any pipe rack structure, that's why Petrochemical and Fertilizer Plants owner may analyses the Pipe Rack structure with dynamic response so that any accident on the plant will cause minor incidents. There is however limited information on the modelling and analysis procedures for dealing with such events.

The basis of this Master thesis is based on a pipe rack structure from one of the leading Petrochemical Plant of Pakistan. The study based on the assumption that the Pipe Rack structure that has to be analysed if any accident or explosion may occur due to hydrocarbon or any other toxic and hazardous gases or liquid and the structural response has also been investigated. Further the Pipe rack Structure is a artery of any plant and all headers will be passing on the pipe rack in any process or Fertilizer plants so the piping is very congested due to which a very strong steel structure for resting of pipes will be designed. I have to perform the linear static analysis of pipe rack on Staad Pro software to calculate the utilization ratio and deflection of the members. Furthermore the Dynamic Study of the Pipe Rack will also be done on Abaqus to check the maximum stresses are in allowable limit. The purpose of the dynamic analysis is to better understand the dynamic behaviour (Such as DAF: Dynamic Amplitude Factor) of the structure due to the any hydrocarbon explosion of pipe on the Pipe rack.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ATTACHMENTS

1.0 Introduction

Pipe racks are steel structures in petrochemical, chemical and process plants that support pipes, instrument cable and electric cables trays[1]. Pipe racks may also support mechanical equipment, vessels and valve, ladders, pressure safety devices and access platforms. Pipe racks are also referred to as pipe supports or pipe-ways. Pipe rack is the main channel for supporting pipes of any plant[2].

Pipe racks are typically long, narrow structures that carry pipe in the horizontal direction. Figure 1-1 show a typical pipe rack used in a plant facility. Pipe routing, maintenance access, and access corridors typically require that the transverse frames are moment-resisting frames[2]. The moment frames resist gravity loads as well as lateral loads from either pipe loads or wind and seismic loads.

Figure 1-1 Pipe Rack

There are two types of Pipe rack [3].

- Continuous Piperacks (conventional pipe rack) system
- Non-continuous Piperacks system

Basically the continuously Piperacks are **Steel Ordinary Concentrically Braced Frames** [4]**.** For these Pipe racks, the lateral stability is provided by diagonal bracing, it consist of two or more columns along with beam where all the pipes are resting and the two columns are joined by side beams usually in the direction of pipe routing[3]. For stability of the structure, the effective length factor K for the compression members shall be taken as unity[5]. Figure 1-2 shows a typical sketch of strutted Pipe rack.

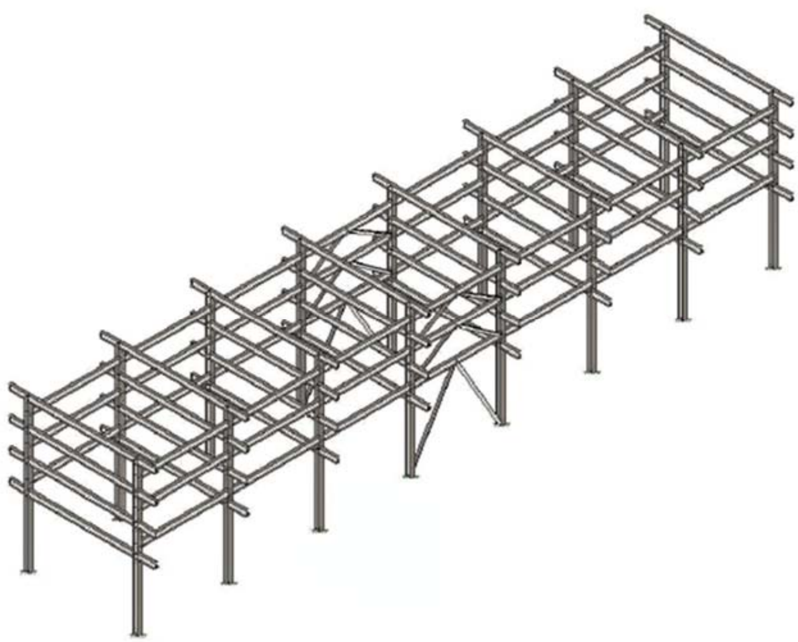


Figure 1-2 Continuous Piperacks

The non-continuous Piperacks are also called as **"unstrutted"** frames [1]. It consists of independent cantilevered, freestanding two dimensional structures that are not depending on longitudinal beams and longitudinal bracing for structure stability[3]. The Lateral Stability for Unstrutted racks shall be depend upon the bending stiffness of rigidly connected beams and columns, the effective length KL of compression members shall be determined by analysis and shall not be less than the actual unbraced length [5].

2.0 Problem Statement

2.1 Introduction

Industrial facilities typically have pipes and utilities running throughout the plant which require large and lengthy pipe racks. Pipe racks are steel structures that are designed to support Pipes, cable trays and several mechanical equipment. The basis of my research is based on a very congested pipe rack structure from one of the leading Fertilizer Plant of Pakistan. The span of pipe rack is 12 meters and the pipe rack is considered of two tiers (floors). Further please refer to Attachment-1 for the CAD modelling of pipe rack. We have to perform the analysis of the pipe rack in two phases. In first phase of the analysis we are performing the conventional analysis of pipe rack while acting all loads (dead load, wind load, live load, friction load, anchor forces and earthquake load). Please see Section 3.3 for the detail description of these loads.

In the second phase of the thesis a study will be performed to analyzed the pipe rack due to explosion occur due to hydrocarbon gas pipe leakage.

2.2 Objectives Of Research

The aim of this research will help to establish the following;

1) To determine the utilization ratio of members.

2) To determine the deflection of the members of piperack.

3) To understand the dynamic behavior of the piperack steel structure (Stresses, Reaction Forces and Displacements) due to Hydrocarbon pipe leakage explosion.

4) To determine the Dynamic Amplification Factor (DAF) of the piperack steel structure exposed due to explosion for Hydrocarbon pipe leakage.

2.3 Significance of Research

Pakistan is a country which produces 4 billion cubic feet of natural gas per day from different oil and Gas Exploration plants. Further there are a large number of Fertilizer and petrochemical facilities in all over Pakistan. Pipe rack is the artery of any plant which supports the transportation of liquids and vapour pipes all over plant. If static analysis is not performed or a method is incorrectly applied, this will be a great hazard for the plant.

By determining the Utilization ratio of a pipe rack, it will give the stresses value of all the members of pipe rack. Further by determining this ratio, the structure will not be over designed which will give a great saving in the steel cost. Deflection on the nodes and reaction forces are also investigated to check the detail properties of members.

Pipes are supporting on pipe rack, if any blast occur on the pipe it will damage the steel structure which also damage the other pipes resting on the pipe rack. By doing this analysis the steel structure will be designed to hold these incidents.

By doing this research we will also determine the Dynamic Amplification Factor (DAF) by comparing the parameters (stresses, displacement or reaction forces) of dynamic and static analysis. The purpose for determining DAF is to see the relationship that exists between dynamic analysis in a blast scenario and its static analysis model. After finding the DAF it will serve as a tool for quickly estimate the deflection, stresses and reaction forces for the dynamic blast by simply calculation the static analysis of any structure.

The shutdown of any process plant will be a financially loss of millions of rupees per day. By doing the above analysis any incident will not cause any damage to other pipes i.e. resting on the pipe rack and shutdown will be for limited time period.

3.0 Literature Review

3.1 Introduction

The Piperack is a steel structure that is built to move the pipe freely on their supports in the horizontal direction (along the axis of the pipe). Further ***Kasi V. Bendapud*** has also discusses about the temperature effects, stability analysis of the pipe racks and the interaction between pipe rack steel structure and the pipes resting on the pipe rack [3].

Pipe rack is a pipe moving space that is assigned for rout several parallel pipes in a process plant. In their research they also analyses the piperack with all loads that is acting on the piperack. Further he has applied two methods for doing seismic analysis of pipe rack which are as follows [4]:

- Displacements due to Inertia Forces
- Differential movements of the column

Piperacks are non-building structures that are designed to support Pipes and cable trays in various plants. In his research he has done stability analysis of pipe rack by three ways [5]:

1. First-Order Analysis Method
2. Effective Length Method
3. Direct Analysis Method

Piping system are considered as main artery of process plants to transfer liquid and gas (hazardous and non-hazardous) which are supported by steel columns and it is very dangerous if any structure may be damage. In his research he has studied the pipes and piperack interaction and how to design a piperack that reduce the amount of material [6].

Pipe supporting structures are actually structures that support pipes used in industrial areas. They have done a seismic analysis of a sample Pipe Rack steel structure by static and dynamically [7].

Pipe rack is structure that supports pipes, cable trays and occasionally supporting mechanical equipments. His research summarizes the building codes (UBC-1997) and industry practice design criteria (ASCE), design loads and other design consideration for pipe racks [8].

Transverse frame that is connected with longitudinal beams then the piperack is considered as strutted. In his research he briefly describes the Seismic parameters and also analyze the piperack by comparing the results with different response factors [9].

A. Khadid et al. [13] calculated the fully fixed stiffened plates under the effect of blast loads to conclude the dynamic response of the plates with different stiffener configurations and measured the effect of mesh density, time duration and strain rate sensitivity. He used the finite element method and the central difference method for the time integration of the nonlinear equations of motion to achieve numerical solutions.

Kirk A. Marchand et al. [14] evaluate the contents of American Institute of Steel Construction,Inc. for facts for steel buildings gives a general science of blast effects with the help of a numbers of case studies of the building which are damaged due to the blast loading. Also studied the dynamic response of a steel structure to the blast loading and shows the performance of ductile steel column and steel connections for the blast loads.

M. V. Dharaneepathy et al. **[**15] review the effects of the stand-off distance on tall shells of different heights, to study the effect of distance (ground-zero distance) of charge on the blast response. An vital task in blast-resistant design is to make a realistic projection of the blast pressures. The distance of explosion from the structure is an vital data, overriding the magnitude and duration of the blast loads. The distance, known as ‘critical6 ground-zero distance’, at which the blast response is a maximum. This critical distance should be used as design distance, as an alternative of any other arbitrary distance.

Ronald L. Shope [16] review the reaction of wide flange steel columns subjected to constant axial load and lateral blast load. The finite element program ABAQUS was used to model with different slenderness ratio and boundary conditions. Non-uniform blast loads were measured. Changes in displacement time histories and plastic hinge formations resulting from varying the axial load were examined.

T. Borvik et al. [17] studied the response of a steel container as closed structure under the blast loads. He used the mesh less methods based on the Lagrangian formulations to lessen mesh distortions and numerical advection errors to explain the propagation of blast load. All parts are modelled by shell element type in LS-DYNA. A methodology has been proposed for the formation of inflow properties in uncoupled and fully coupled Eulerian–Lagrangian LS-DYNA simulations of blast loaded structures.

TM 5-1300 (UFC 3-340-02) [18] is a manual titled “structures to resist the effect of accidental explosions” which provides assistance to designers, the step-to-step analysis and design procedure, with the information on following items

(1) Blast, fragment and shock loading.

(2) Principle on dynamic analysis.

(3) Reinforced and structural steel design and

(4) A number of special design considerations.

T. Ngo, et al.**[**19] for their study on “Blast loading and Blast Effects on Structures” gives an summary on the analysis and design of structures regarding blast loads phenomenon for understanding the blast loads and dynamic response of a variety of structural elements. This study helps for the design concerns against severe events such as bomb blast, high velocity impacts.

DNV-OS-C201 [36] is a manual titled "Structural Design of Offshore Units" which presents technical requirements and assistance for the structural design of offshore structures, based on the Working Stress Design (WSD) method.

The objectives of this standard are to:

- Present an internationally adequate level of safety by defining minimum requirements for structures and structural components (in combination with referred standards, recommended practices, guidelines, etc.)
- serve as a contractual reference document between suppliers and purchasers
- serve as a instruction for designers, suppliers, purchasers and regulators
- State the procedures and requirements for offshore structures subject to DNV certification and classification.

DNV-RP-C204 [20] is practice manual titled as "Design against Accidental Loads" which give Recommended Practice of design to maintain the load-bearing function of the structures during accidental events. The overall goal of this manuals to design structures against accidental loads and to achieve a system where the main safety functions of the installation are not compromised.

3.2 Conclusion of the Literature Review

A number of researches has been carried out about the pipe rack and its analysis which are mostly statically, number of articles are present for only seismic and wind load calculation of pipe rack. Several research on blast loads are also been done on structure but the nature of the blast and structure are different. There is however limited information available about the dynamic analysis of pipe rack for any hydrocarbon leakage in pipe resting on pipe rack.

3.3 Primary Loads

For doing Pipe rack analysis we have considered following loads [6].

- D_L - Dead Load
- LL - Live Load
- Pt - Test Load
- Ff-Friction Forces
- AF-Anchor Forces
- WL - Wind Load
- E – Seismic Load

The brief description of the above loads is as follows:

3.3.1 Dead Load (D_L)

- Dead load comprises of all pipes empty load including insulation weight (if any). The weight of Cable trays, switchgear, fireproofing and instrumentation etc. are also to be considered under dead load.

- The selfweight of steel structure pipe rack and steel sections, supporting platforms, ladders are also included in Dead Load.

3.3.2 Operating dead load (Do)

The operating dead load is the working plant operation load of pipe rack when comprises of the, piping weight, pipe insulation weight, cable tray weight and other equipment's with the fluid load. The piping and cable tray loads may be based on actual weight or approximated by using uniformly distributed loads.

3.3.3 Empty dead load (De)

The empty weight of piping, piping insulation, cable tray, process equipment and vessels. When using approximate uniform loads, 60% of the operating dead load for piping levels is typically used. Engineering judgment should be used for cable tray levels.

3.3.4 Test dead load (Dt)

The empty weight of the pipes plus the weight of the test liquid (generally water is used as a liquid).

- Based on the future expansion of the plant 10% empty space will be taken for future pipes.

- For future Pipes load, 1.10kPa shall be use for design or equivalent to 8" inch pipe load will be acting on the empty portion of the piperack.

- Dead loads mat be act as a concentrated loads and shall be calculated using the following equation:

$$P_{DL} = S\,(W_{DL} - P_{DL}\,D)$$ ***Equation 3-1***

Where:

S = Pipe support spacing (ft)

W_{DL} = Large pipe weight per foot (plf)

P_{DL} = Average pipe deck loading (psf)

D= Large pipe diameter (ft)

3.3.5 **Live Load (L_L)**

- Live load shall be described that the gravity forces imposed by the liquid or viscous material in piping during plant operation.

- Piperacks shall be designed for present and future live loads. Live loads shall not be less than the following:

  a. Minimum Live loads of 0.81 kPa shall be taken at each level for the designing of piperack.

  b. Live loads mat be act as a concentrated loads and shall be calculated using the following equation:

$$P_{PL} = S\,(W_{PL} - P_{PL}\,D)$$ ***Equation 3-2***

Where:

S = Pipe support spacing (ft)

W_{PL} = Large pipe product load per foot (plf)

P_{PL} = Average product loading (psf)

D = Large pipe diameter (ft)

c. For future Pipes Live load, 8" pipe load (filled with water) will be acting on the empty portion of the piperack.

3.3.6 Test Load (Pt)

The test load shall be defined as the gravity weight imposed by the liquid (generally water) used to pressure test. Large vapor lines may require hydrotesting. This method may be possible to test them one at a time on the piperack while the other lines on the pipe rack are kept empty which avoid the heavy pipe support loading. The method of analyzing the steel structure with hydrotest load is to analyze the steel structure with the large pipe line filled with water [6].

3.3.7 Thermal Loads

Forces produced by the variation in the temperature of piping are Thermal loads. For the designing of piperack, both ***friction forces*** (F_f) and ***anchor forces*** (A_F) shall be considered. For thermal expansion and contraction of pipes, pipe rack must be designed to resist longitudinal loads. Due to the long distance of piperack, different lines expand and contract at random times. Thermal loads are applied to the transverse members either through friction or through pipe anchors.

3.3.8 Friction Forces (Ff)

Friction forces results due to the hot pipe lines sliding across a pipe support during start-up and shut-down of pipe are assumed to be partly resisted by adjacent cold pipe lines. The resultant longitudinal friction force (Ff) shall be taken as following:

a. 10% of the total working weight of all pipelines resting to the support

b. 30% of the total working weight of those pipe lines resting to the support, which will contract or expand simultaneously.

The 10% of the total piping weight resting to the support shall be taken as an expected longitudinal friction forces (FF) applied only to local supporting beams.

During Load combination friction loads of the pipe shall not be combined with earthquake or seismic loads for the design of piperack, braced anchor frames, columns, and foundations, when there are multiple frames. During high seismic load or wind load, the deflection and vibration of the supports under load will likely relieve the friction forces.

3.3.9 Anchor Forces (AF)

Guide forces occur due to the use of channels or horizontal bracing as well vertical bracing at anchor bents. Pipe anchor and guide forces (AF) results due to thermal expansion and internal pressure. Anchor forces should not happen too frequently since Piping Engineer like to anchor large lines on only a few bents in a header. Anchor forces values and its location shall be obtained by the flexibility analysis of the pipe line. Anchor and pipe forces shall be obtained from the checked pipe stress analysis computer run.

Piperack shall be designed to resist actual pipe anchor loads. Anchor Forces (excluding their friction component) shall be combined with Earthquake or Wind loads.

3.3.10 Wind Load (WL)

- Wind loads on all pipe, cable trays, Process equipment, steel structure, cable trays, platforms and ladders to the piperack shall be considered in calculating the wind load on the pipe rack. Wind pressures, wind pressure distribution, and pressure coefficients shall be computed and applied in accordance with ASCE 7 - 95.
- The total wind load/ft on pipes, W, can be determined through following equation (ASCE 7 -Table 6-1):

$W_L = q_Z \, G \, C_f \, A$ ***Equation 3-3***

where:

q_z = 0.00256 K_Z K_{Zt} V^2 I (lb/ft²) (ASCE 7 - Eq. 6-1)

I = Importance Factor

V = Wind Velocity (MPH)

K_Z = Exposure Coefficient

K_{Zt} = Topographic Factor (per ASCE 7 provision 6.5.5).

K_{Zt} = 1.0 for Piperacks

G = Gust Response Factor

C_f = Force Coefficient

A = Projected Area normal to wind

- Wind load shall be calculated on the column section For piperack, the design lateral wind load on pipes shall be calculated on the largest weight at each pipe tier.
- Longitudinal wind load on piperack shall be taken as negligible compared to other longitudinal forces.

3.3.11 Earthquake Load (E)

Earthquake loads shall be calculated and applied in accordance with ASCE 7 - 95. The earthquake loads in ASCE 7 are limit state seismic loads and this should be taken into account when using allowable stress design methods and applying load factors from other codes, etc. [8]

The Importance Factor ‘I’ and other Factors for Calculating Earthquake Load will be considered from Chapter-15 of UBC-1997 (Uniform Building Code).

The dead loads and live loads of pipes, cable trays and other equipment resting on the pipe rack will also be considered for calculating the Earthquake effects on the pipe rack. Usually 100% of the dead load s of the pipes will be considered and 25% of the live load values of the pipes will be taken for calculating Seismic Loads.

3.4 Loading Combinations – Allowable Stress Design

The load combinations of primary loads mentioned below are used in the allowable stress method of design (ASD). The load combinations mentioned below are the most common load combination that is used in the analysis of steel structure but it may not cover all possible load combinations. Any load combinations that could change the maximum stress or any load combination that can govern the stability of the pipe rack should be included in the calculations. [6]

$D_L + L_L + F_f + A_F$ (if any) — ***Load Comb. 1***
(Max. Operating Gravity Loads)

$0.75(0.9\, D_L + W_L)$ — ***Load Comb. 2***
(Min. Dead Load + Wind)

$0.75(D + L_L + AF + W_L \text{ or } E)$ — ***Load Comb. 3***
(Max. Oper. Gravity + W or E)

$0.80\, [D + P_t + (1/4\, W \text{ or } 1/4E)]$ — ***Load Comb. 4***

(Test Load + W or E)

- The factors considered in these load combinations is as per code UBC-1997 [8].

- Wind forces and seismic loads shall not be considered to act together in a load combination.

- For Load Combination # 4, 25% of the Seismic Load or Wind load needs to be considered. Further Hydrotest of the pipes are not conducted during high winds, and the shock of seismic loads during hydrotest is low.

By using above load combinations for Allowable Stress Design Method following properties of the structure elements will be investigated.

3.4.1 Utilization of structural steel

Austin [9] states that ***'the prime objective of an engineer is to produce a robust solution … in the most economic and practical way possible'***. To reduce the steel costs in structures require an understanding of structural design and construction economics [10].

A "Utilization Ratio" (abbreviated to UF; also called Unity Factor or Utilization Factor) is defined as the ratio of the actual stress to the Maximum allowable stress value.

$$\text{Utilization Ratio} = \underline{\text{Actual Stress}}$$ ***Equation 3-4***

Maximum Allowable Stress

UF ratio can be calculated for a range of performance requirements for steel elements (beams or columns). For any steel member, design engineers are worried with the highest UF ratio across all forces and moments requirements of the steel member. For e.g. the bending stress of the particular steel member is the highest value and the allowable stress is its maximum capacity that resist the failure of the steel member. Design standard (AISC-ASD) solve all the performance requirement parameters with specific calculations, instructions and specify the UF ratio as one(unity) [5].

By determining the UF ratio of a structure element, it also indicates its excess capacity—i.e. the material that is unnecessary. For e.g. in analyzing the structure, unity ratio of structure element is less than 0.9 which indicates that excess material or strong sections has been used which is unnecessary. Due to unity factor ratio the structure will not be over designed which will give a great saving in the steel cost which also saves the installation cost of structures. Further the unity ratio gave us a parameter to check all the structure elements behavior and reinforcement (if any) will be done by the help of this factor to any particular element. For simplicity of calculation, it was assumed that steel requirements were directly proportional to unity ratio for both composite and non-composite elements.

3.4.2 Deflection in Structural Steel

Structures such as buildings and pipe racks contain a number of components such as beams, column, bracings, connecting plates and foundations which all act together to ensure that the loadings that the structure carries is safely transmitted to the supporting ground below.

Normally the material used for beams and columns in Pipe racks is carbon steel and have a cross sectional shape that can be rectangular H,T or I shape. These beams should be design in such manner that it can sustain the load without any failure.

In addition to the requirements for the beam to safely carry the intended design loads, there are other factors that have to be considered including assessing the likely deflection of the beam under load. If beams deflect excessively, then this can lead to damage of parts of the pipe racks or any explosion will occur due to the structure damage.

4.0 Explosion Incident on Pipe Rack

Any blast on a plant is the result of major accident which together creates a chain reaction leading up to the final explosion. Any accidental release of a gas or liquid will create a fire.

However if the gas or liquid releases on a pipe rack, it may lead to formation of a combustible fuel-air cloud, which after ignition will create a hydrocarbon explosion.

The primary objectives for assessing blast scenarios and to provide blast resistant designs are [12]:

- Personnel safety
- Controlled shutdown
- Financial considerations

Blast resistant design should provide a level of safety for persons in a plant. Preventing cascading events due to the loss of control of process units not involved in an accident is another important objective in blast resistant design. A blast incident in one processing area should not be allowed to affect the safe operation or shutdown of other units or areas. Preventing or minimizing financial losses is another objective of blast resistant design.

Further the emergency shutdown of any pipe on the pipe rack when the valves are resting on the rack is not possible on a small amount of time due to the limiting amount of ladders and also the huge length of pipe rack. That's why Petrochemical and Fertilizer

Plants owner may analyses the Pipe Rack structure with dynamic response so that any accident on the plant will cause minor incidents.

The explosion happen in chemical facilities such as in onshore and offshore oil and gas plants are very rare but the consequences are huge. It is the responsibility of the structure engineer to understand the explosion behavior and how it will affect the steel structure.

4.1 Definition of an explosion

An explosion is an incident due to a raise in pressure and is cause by one or a combination of the following incidents [21]:

- nuclear reactions
- loss of containment in high pressure vessels
- explosives
- metal water vapour explosions
- run-a-way reactions
- combustion of dust
- mist of gas (including vapour) in air or in other oxidisers.

The basis of thesis is to examine only the chemical explosion as a result of flammable gas, due to gas explosion in any hydro carbon pipe rested on the pipe rack. In such type of explosion two modes can be derived: detonation and deflagration [22].

4.2 Deflagrations and detonations

Deflagration type explosion is most common type which can be define as the wave propagation at a velocity below the speed of sound i.e. subsonic speed [21]. In Deflagration type explosion the speed ranges from 1-1000m/s, while detonations are considered as more extreme and represent shock waves moving in the supersonic range (1000-2000 m/s). Figure 4-1 shows a pressure variation graph for a typical gas explosion of the deflagration type, while a very powerful gas explosion is in the detonation range.

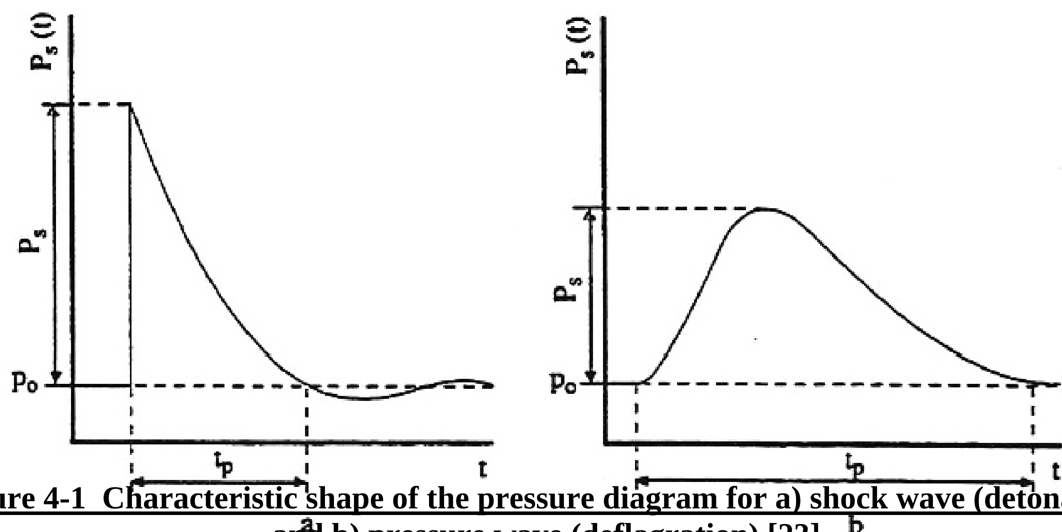


Figure 4-1 Characteristic shape of the pressure diagram for a) shock wave (detonation), and b) pressure wave (deflagration) [23]

Where,

a=time period of shock wave

b=time period of pressure wave

P_o=Zero Pressure

P_S=Maximum Pressure of Blast Wave

A detonation is characterized by an instantaneous pressure rise (no rise time), and often a negative pressure after positive phase duration. The negative pressure in the graph can be considered as negligible because the negative pressure magnitude is much smaller then the positive peak overpressure.

A deflagration mode of blast is characterized by a rise time and a slower decrease to zero within the positive phase duration time. The pressure diagram of both blast modes are shown in Figure 4-2.

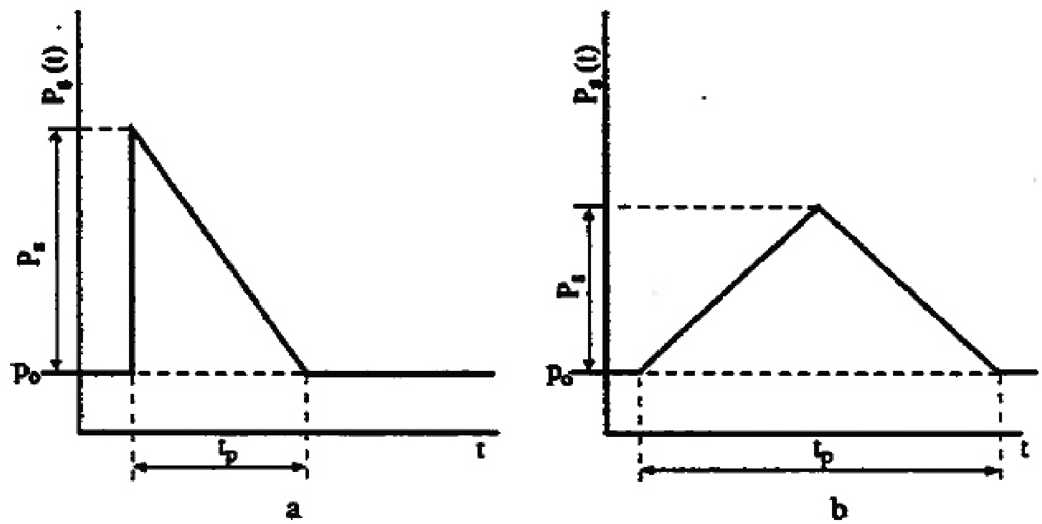


Figure 4-2 Simplified pressure diagram for a) shock wave (detonation), and b) pressure wave (deflagration) [23]

Where,

a=time period of shock wave

b=time period of pressure wave

P_o=Zero Pressure

P_S=Maximum Pressure of Blast Wave

4.3 Interaction between blast and structure

In explosion due to flammable gas in air due to blast in pipe rested on pipe rack due to deflagration in heavily packed and confined areas such as inside building or pipe rack.

In estimate or calculation of deflagrations, peak pressure, rise time, the duration of the pressure pulse and the impulse should be considered. If a blast occur in the process area then the blast wave magnitude will be depending on the following parameter.

- the pressure and duration of the explosion
- the distance between the explosion and the structure.

4.4 Side-on pressure and reflected pressure

The side-on pressure is the pressure measured perpendicular to the direction of the blast wave direction [21]. When the blast wave impacts a structure, all flow behind the front is stopped which will result in a reflecting pressure that is considerably greater than the side-on pressure [24]. Figure 4-3 illustrates a blast wave propagating towards a solid structure where the shock front is reflected when the blast wave hits the front face.

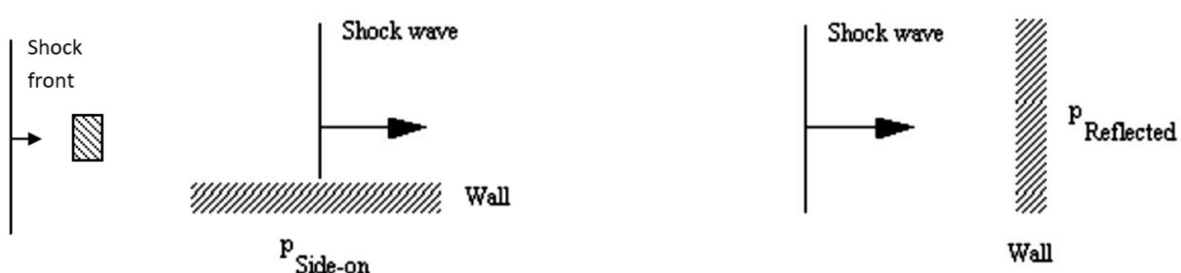


Figure 4-3 A shock front moves towards a small (left) and a larger (right) object and is reflected as it hits the wall facing the direction of the blast wave [21].

For objects with small dimensions as the one on the left in Figure 4-3, the shock front moves so quickly that reflection does not have to be considered [25].

The directions of the side-on pressure and the reflected pressure are illustrated in Figure 4-4, where the reflected pressure is directed in the propagation direction of the blast wave.

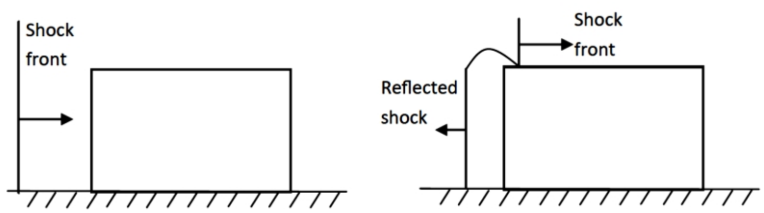


Figure 4-4 Side-on pressure and reflected pressure [21]

4.5 Dynamic pressure

When a blast happens in a steel structure it will create a dynamic wind load on the structure in the direction of the wind. Dynamic wind load results and air displacement in the direction of the blast-wave. The air displacement due to blast load is referred to as an explosion wind that causes a dynamic pressure which can be calculated from the following formula:

$$P_D = CD \times 0.5 \times \rho_s \times U^2 \text{ [35]} \qquad \textbf{\textit{Equation 4-1}}$$

Whereby: P_D is the Dynamic Pressure and its unit is Pascal. CD is the so-called drag coefficient, which is dependent on the shape of the structure (projected area) and its orientation relative to the blast front. Figure 4-5 shows the different values of CD given for various simple structural shapes. ρs is the air density within the blast (kg/m3), and us(t) is the velocity of the air particles (combustion products) (m/s)

Table I. Coefficients C_D. Taken from [2]

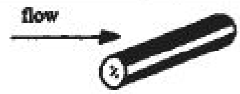
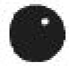
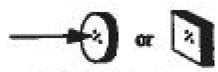
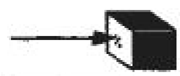
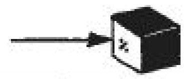
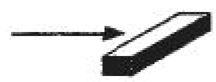
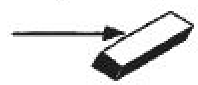
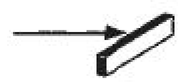
Shape	Figure	C_D
Long Straight Cylinder		1.20
Sphere		0.47
Cylinder		0.82
Disc		1.17
Cube		1.05
Cube		0.80
Oblong Box		2.05
Oblong Box		1.55
Strip		1.98

Figure 4-5 Drag coefficients given for various simple structural shapes [23]

It should be noted that the dynamic pressure exerts the dominant blast effect on open frame structures, framed structures with frangible cladding, and on small structures.

4.6 Pressure Distribution and Magnitude

As previously mentioned in this chapter, the reflection pressure can therefore be neglected, and the only relevant pressure to be taken account for in the analysis will be the dynamic pressure P_D.

The dynamic pressure can be calculated from equation 4-1. If we assume a hydrocarbon gas explosion being in the deflagration range, the velocity of the combustion particles are to be assumed to be travelling in subsonic speed (less than343 m/s). According to [30], typical combustion gases found on an offshore processing facility are ethane, propane, butane and methane. These have vapor densities in the range of roughly 0.5-2 kg/m^3.

Predicting the magnitude of the different variables in the calculation of the dynamic pressure for a blast scenario is a complicated task. Tabulated values of the drag coefficient, C_D is only given for simple geometries such as a box or a cylinder. The velocity and the density of the combustion particles during a deflagration blast is very hard to determine as these depend on many factors. However, simplifications can be made as to give a first estimate. According to [31], the major portion of the loading on an open-frame structure is the drag pressure contribution. The drag coefficient CD for an individual member such as a I-beam is about 1.5, however when the whole frame is considered it has been suggested to reduce CD to 1.0. This is because various members shield one another to a certain extent from the effects of the full blast loading. If we assume the explosion gas to be represented by ρs = 0.5 kg/m3, and with an air velocity just under subsonic (340 m/s), CD equal to 1.0 we get a dynamic pressure of roughly 0.3 bar. The proposed design value (DAL) for the dynamic pressure as given by Aker Solutions is between 0.2 and 0.4 bar [32].

5.0 FEA in Abaqus/CAE

In order to perform dynamic analyses of the pipe rack software Abaqus has to be used. CAE is an abbreviation of Complete Abaqus Environment and consists of the Abaqus software application package with modeling, processing, analysing and visualisation tools in the same program. The content of the chapter is based on the Abaqus/CEA User's Manual available online.

This content of this chapter includes general geometry, boundary conditions (BCs), element type, material properties and loads as well as supplementary assumptions such as blast duration. In Figure 5-1 the 3-D FEA model of the pipe rack is illustrated.

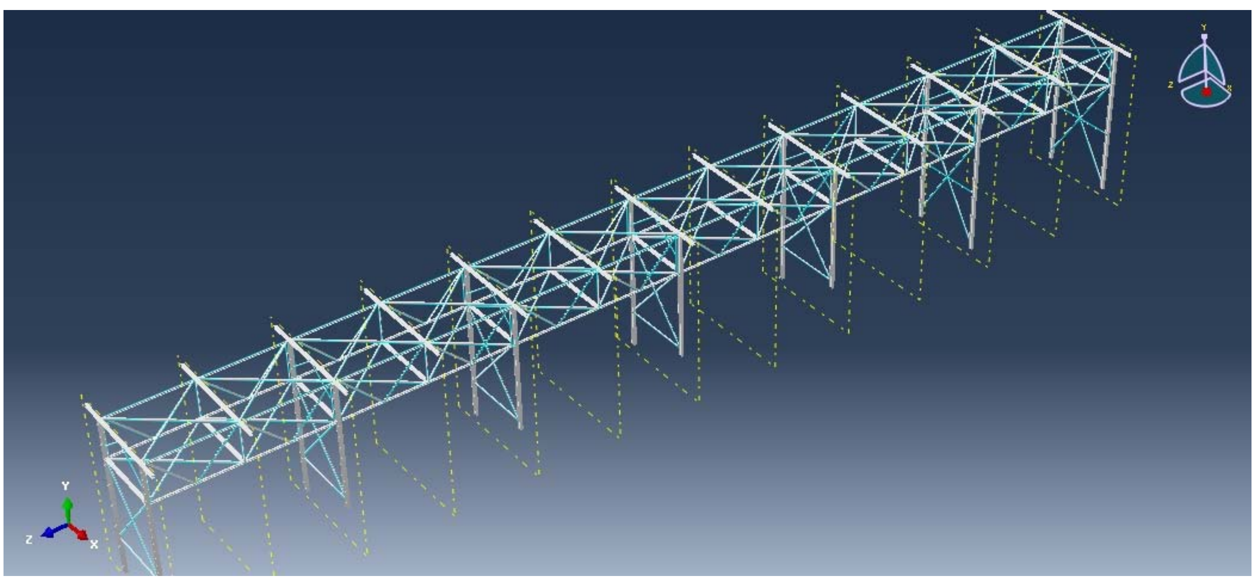


Figure 5-1 3-D Model in Abaqus

5.1 Methodology

There are no readymade pipe rack models in ABAQUS for time dependent analysis, however there is a way to create own geometry model. Further ABAQUS uses several subroutines, programmed in FORTRAN language, to permit the user to define his own material model. The following scheme (Figure 5-2) describes the modelling and calculating processes used for analysis of Pipe rack in the present study.

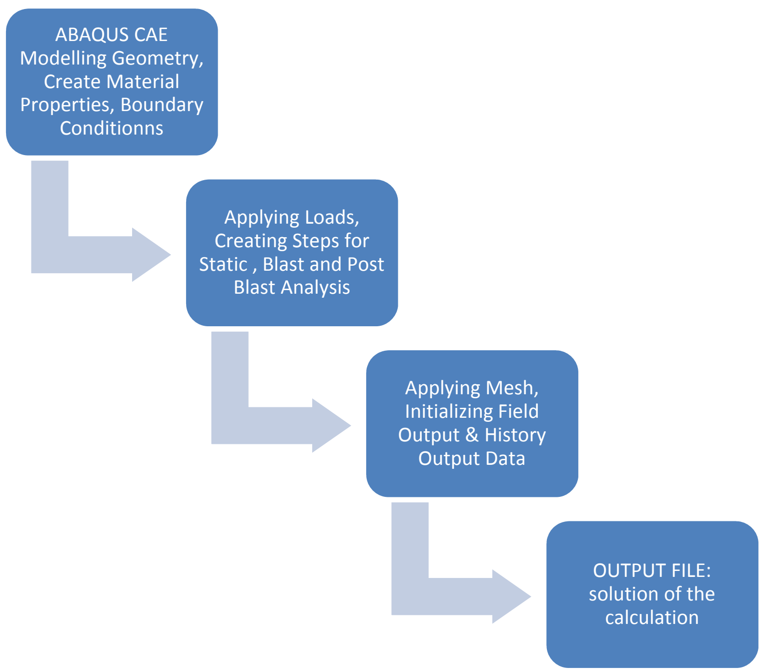


Figure 5-2 Methodology for Pipe Rack Analysis

5.2 Modeling of Geometry

The pipe rack structure was modeled as wire elements with given sectional profiles corresponding to the correct dimensions as from the drawings provided by the industry.

Five different European Sections profiles are used:

- HEA-200
- HEA-240
- HEA-120
- Half IPE-200
- Angle 100x100x8
- Angle 50x50x8

Detail properties of these sections and angles are attached in Attachment-II.

The non-linear geometry (Nlgeom) setting has been applied to all elements.

5.3 Material settings

All structures are designed with steel S355 and a non-linear behaviour as illustrated in Figure 5-4. There are different ways of measuring the stress and strain for steel. From material testing the results are often given as "engineering" stress-strain curves, while for use in FEA the "true" stress-strain curves are recommended [20]. For that reason the "true stress" is used for all analyses presented in this report. Figure 5-4 is generated from values given in (DNV, 2013) and illustrates the difference between "true" and "engineering" stress-strain relationships for S355.

Elastic material properties have been assigned to the static analysis model, while material non-linearity has been accounted for in the dynamic model, by establishing an elasto-plastic material in Abaqus. The classical metal plasticity model in Abaqus is intended for applications such as crash analyses, metal forming, and general collapse studies [33].

It should also be noted that the plasticity model in Abaqus must be used in conjunction with the linear elastic material model, and that true (Cauchy) stress and log strain values are to be used [34].

Nominal stress (engineering stress) is calculated assuming the cross-sectional area not to change during deformation; this is a valid approach if the expected deformations are small. However for a case with large deformations, the change in cross-sectional area is significant and true (Cauchy) stress has to be implemented. We see from Figure 5-3 and Figure 5-4 that both nominal and true stresses are almost identical and linear elastic up to the yield strain. After this point, the true stress is larger than the nominal stress when the strain increases. This is due to the reduction of the cross sectional area due to deformation.

The proposed non-linear properties for True stress-strain and engineering Stress-strain as recommended (DNV, 2013) are listed below:

Table 5-1 Proposed non-linear properties for S355 steels (True stress strain) [20]

Thickness [mm]	t < 16	16< t < 40	40 < t < 63
E [MPa]	210000	210000	210000
S_{prop} [MPa]	320.0	311.0	301.9
S_{yield} [MPa]	357.0	346.9	336.9
S_{yield2} [MPa	366.1	355.9	345.7
S_{ult} [MPa]	541.6	541.6	518.5
e_{p_y1}	0.0040	0.0040	0.0040
e_{p_y2}	0.0197	0.0197	0.0197
e_{p_ult}	0.1392	0.1392	0.1392

Table 5-2 Proposed non-linear properties for S355 steels (Engineering stress-strain) [20]

S355			
Thickness [mm]	t < 16	16< t < 40	40 < t < 63
E [MPa]	210000		
S_{prop}/S_{yield}	0.9		
Ep1/E	0.001		
S_{prop} [MPa]	319.5	310.5	310.5
S_{yield} [MPa]	355	345	335
S_{yield2} [MPa]	358.4	348.4	338.4
S_{ult} [MPa]	470	470	450
e_{p_y1}	0.004		
e_{p_y2}	0.02		
e_{p_ult}	0.15		
E_{p2}/E	0.0041	0.0045	0.0041

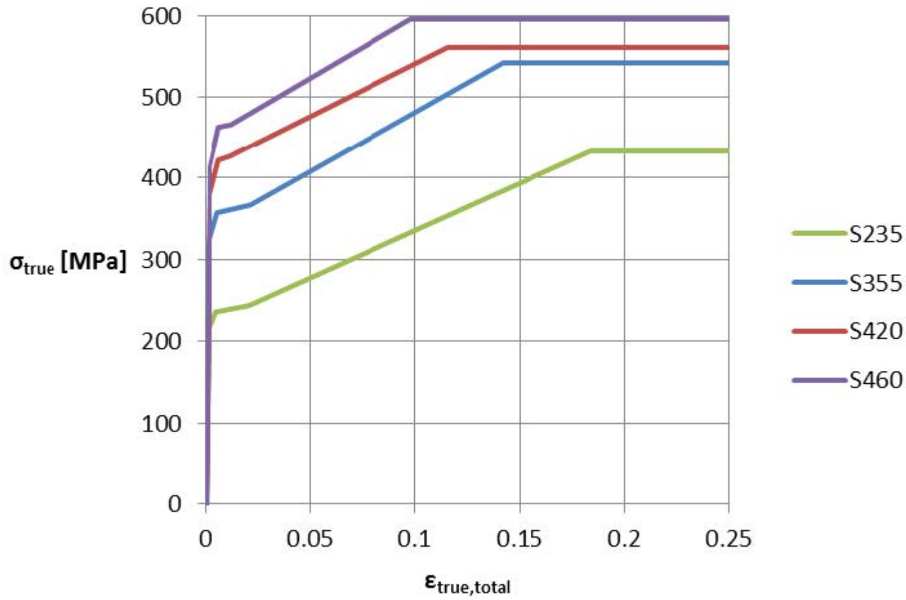


Figure 5-3 Engineering Stress- Strain Curve of S-355 material [20]

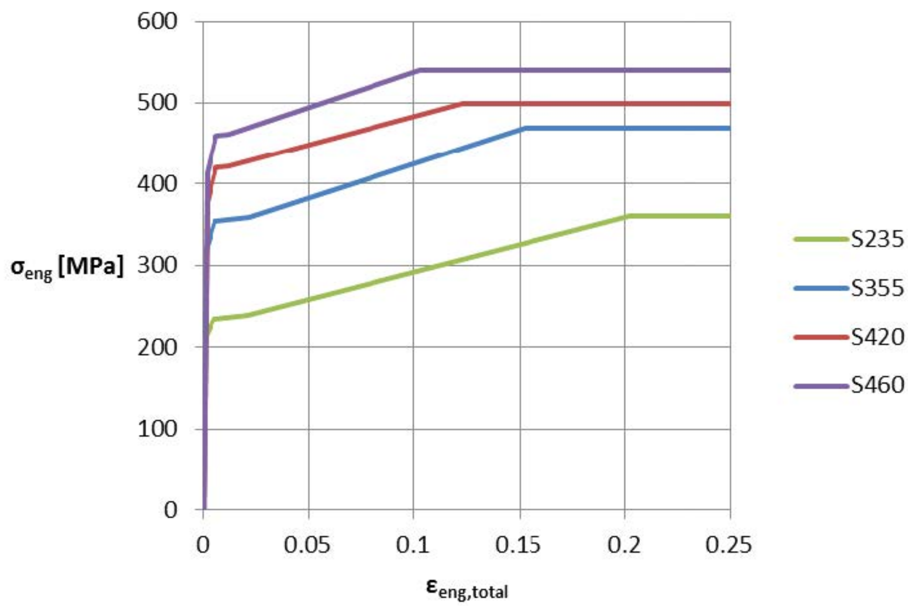


Figure 5-4 True Stress- Strain Curve of S-355 material [20]

5.4 Boundary Conditions

Steel Structures transmit their loading through a series of elements to the ground. This is fulfilled by joining steel elements at their intersections. Each connection is designed so that it can transfer, or support, a specific type of load or loading condition. For analysis of structure, it is first necessary to be clear about the forces that can be resisted, and transferred, at each level of support throughout the structure. The actual behaviour of a support or connection can be quite complicated and if all of the various conditions were considered, the design of each support would be a terribly lengthy process.

For our pipe rack we considered pinned supports which means that the column is fixed in 3DOFs ($\sum Fx=\sum Fy=\sum Fz=0$) whereas the moments are considered to be free. An overview of the boundary conditions imposed to the model in Abaqus is found in Figure 5-5Figure 5-5.

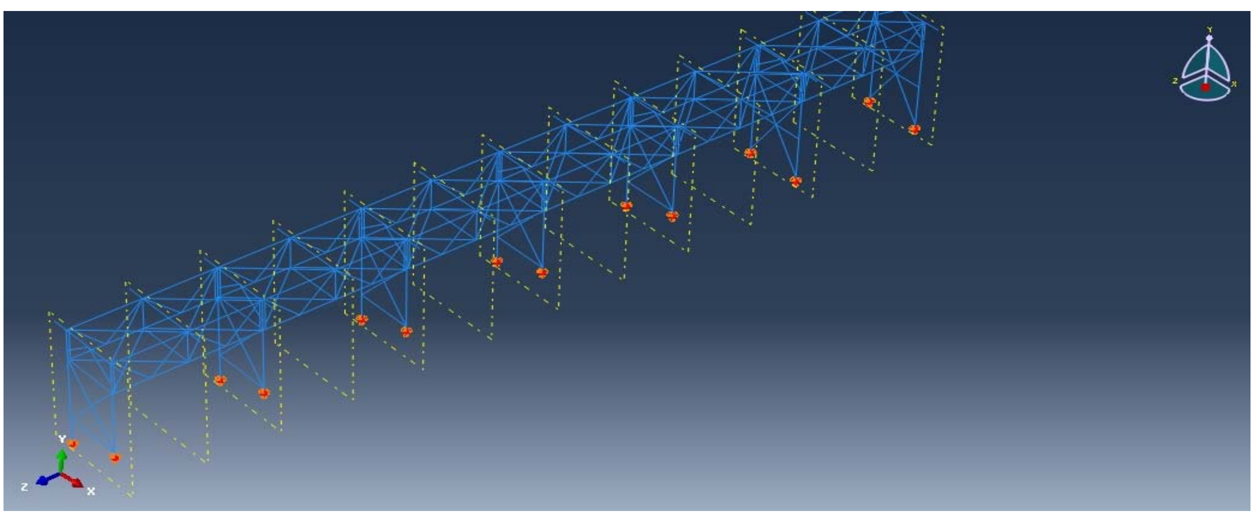


Figure 5-5 Boundary Conditions in Abaqus

5.5 Selfweight of Strcture

The selfweight of structure in abaqus are applied in all steps(Self weight and Pipe weight, Dynamic Blast Analysis and Post Blast Analysis), that's why we have created this load on self-weight and Pipe weight step and propagated in other two forwarded steps. In applying the self-weight of structure we have applied the gravitation acceleration load in (-ve) Y-direction on the overall structure as shown in Figure 5-6.

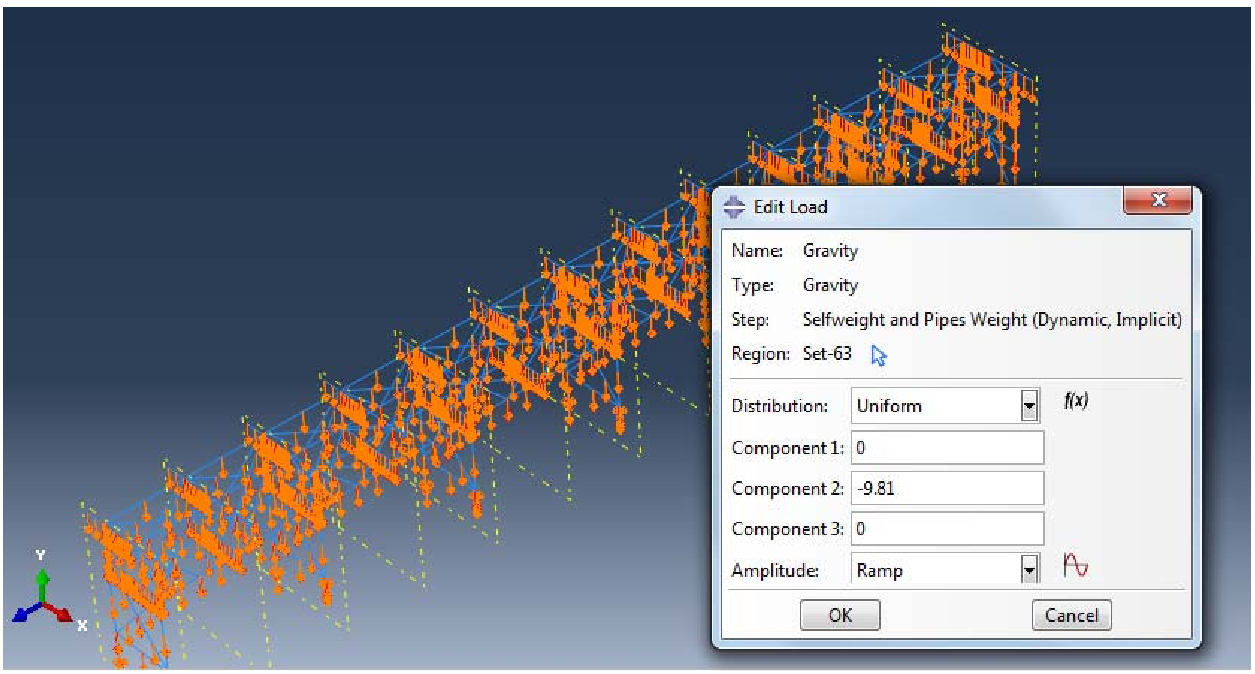


Figure 5-6 Gravity Loads in Abaqus

5.6 Pipe Loads

The pipes loads are applied on abaqus in all steps. Three types of pipes load are applied which are as follows:

- Dead Load
- Live Load
- Friction Load

All these loads are briefly defined in section 2.3. Dead and Live loads are applied in –Y direction whereas friction loads are applied in longitudinal direction (opposite direction of flow). These loads are applied on the main beam of the pipe rack. As the concentrated loads are not applied in abaqus on the middle of beam so nodes are created where pipe is resting.

5.7 Wind Loads

Wind loads has been briefly discussed in Section 3.3.10. By consider the design speed of 100mile/hr wind loads are calculated from ASCE equation. Wind loads are applied uniformly on the column as well as point load on the beam.

5.8 Pressure Load

When using a wire element assigned with a profile, a uniform distributed load is applied in Abaqus on the steel sections using a line load. A pressure load is applied as a uniform load over the wire element (unit=N/m). Because the dynamic pressure is expressed in Pascal, it is multiplied with a characteristic element European profile section height to obtain the correct line load. For this pipe rack, three type of European profiles sections are used; HEA-240, HEA-200 and HEA-120. Meaning that the cross-section heights of the profiles are 230,190 and 114mm respectively.

- Dynamic pressure = 0.2 bar = 2 x 10^4 P a (N/m^2)
- Dynamic pressure = 0.4 bar = 4 x 10^4 P a (N/m^2)

The line loads corresponding to these pressures (on HEA-240) are thus:

- Line load (0.2 bar) = 20 000 x 0.230 m = 4,600 N/m
- Line load (0.4 bar) = 40 000 x 0.230 m = 9,200 N/m

The line loads corresponding to these pressures (on HEA-200) are thus:

- Line load (0.2 bar) = 20 000 x 0.190 m = 3,800 N/m
- Line load (0.4 bar) = 40 000 x 0.190 m = 7,600 N/m

The line loads corresponding to these pressures (on HEA-120) are thus:

- Line load (0.2 bar) = 20 000 x 0.114 m = 2,280 N/m
- Line load (0.4 bar) = 40 000 x 0.114 m = 4,560 N/m

The line load has been applied to the whole structure as shown in Figure 5-7 Line Loads in Abaqus. Simplification on the effects of shielding has been taken account for by using a drag coefficient CD equal to 1.0, as suggested in section 4.6.

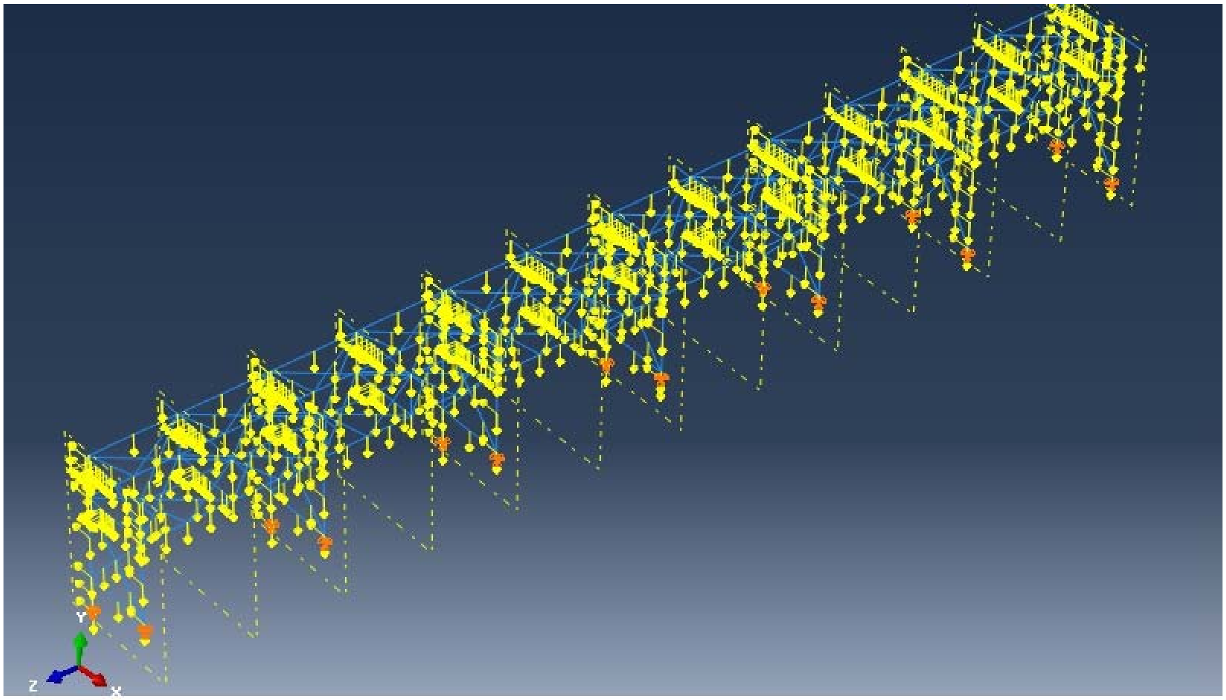


Figure 5-7 Line Loads in Abaqus

Because a dynamic analysis is time-dependent, it is necessary to create a time-varying load profile in Abaqus to correctly represent the effects of the blast load. The amplitude toolset in Abaqus has been used to define the pressure load profile for the dynamic analyses. By using the tabular feature, the load profile was defined by directly giving the input values for a profile amplitude corresponding to a specific time. This is illustrated in Figure 5-8 and Figure 5-9 for the pressure load profile for the 100 ms blast.

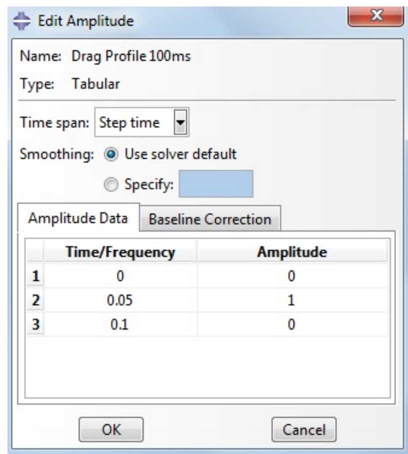


Figure 5-8 Drag Profile Amplitude in Abaqus

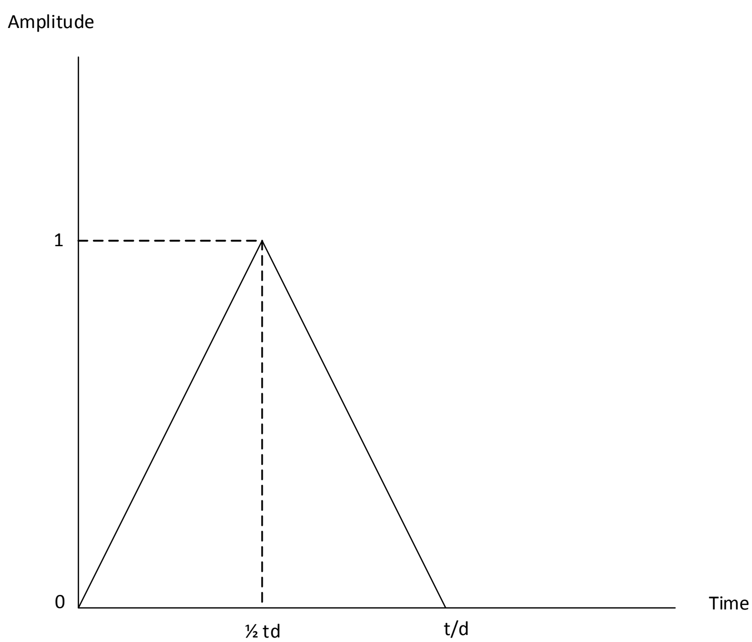


Figure 5-9 Drag Profile during Blast [35] given by Biggs

5.9 Loads and load sequences

The load and load sequences in Abaqus/CAE are organised as steps in order to define specific parameters such as loads and BCs for separate sequences of the analyses. In the performed analyses the load sequences are divided into four steps.

In addition the initial step, 3 other steps are present in the analysis. These are:

- Self-weight and Piping weight (gravity load, mass from pipes)
- Blast Load. Different step duration depending on duration of blast (i.e 50, 100, 150 or 200 ms)
- Post-blast (only gravity and piping load is set active, whereas blast load is set inactive)

5.9.1 Initial step

In the initial step the BCs for the structure are created. These BCs are in the succeeding steps propagated from the initial step as they maintain constant throughout the analyses. The setup in the “Boundary Condition Manager” is depicted in Figure 5-5.

5.9.2 Self-weight step

The "Self-weight" step is is defined as “Static-General” where the gravity (structural self-weight of the structure) and piping weight is applied linearly on the structure and the load amplitude set to “Ramp” as shown in Figure 5-10.

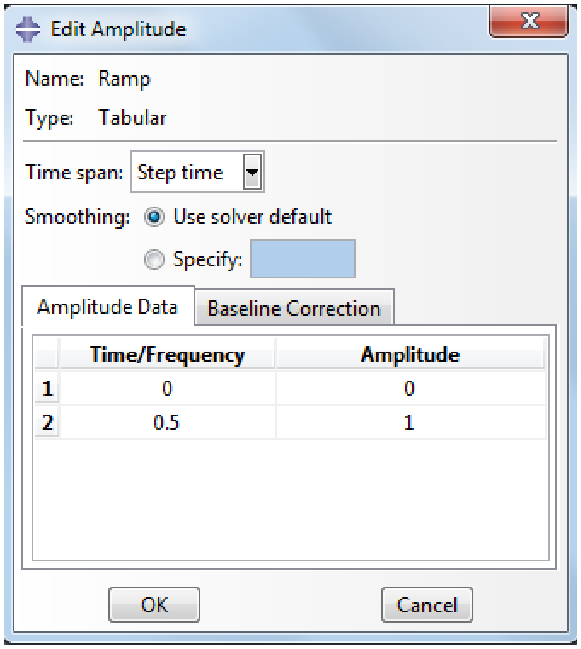


Figure 5-10 Ramp Profile Amplitude in Abaqus

5.9.3 Dynamic Blast Step

The blast load step is defined as "Dynamic Implicit" and the loads are applied with a triangular blast pulse curve. Dynamic analyses in Abaqus/CAE can be done either by choosing "Dynamic implicit" or "Dynamic explicit" as calculation procedure. The differences between the two methods, the implicit calculation procedure uses a simpler algorithm for the analyses than the explicit, resulting in a reduced CPU-time. As the pipe racks are modelled with beam elements, an implicit calculation can safely be chosen. Due to negligible inertia forces quasistatic type analysis is considered.

To obtain a smooth DAF-curve, the FE-analyses are executed with blast durations varying from 50 ms to 200 ms. The blast duration is changed by defining the amplitude of the blast pulse in the amplitude toolbox in Abaqus/CAE as depicted in Figure 5-9. In accordance with Biggs curve, the blast pulse is defined as a triangular symmetric pulse.

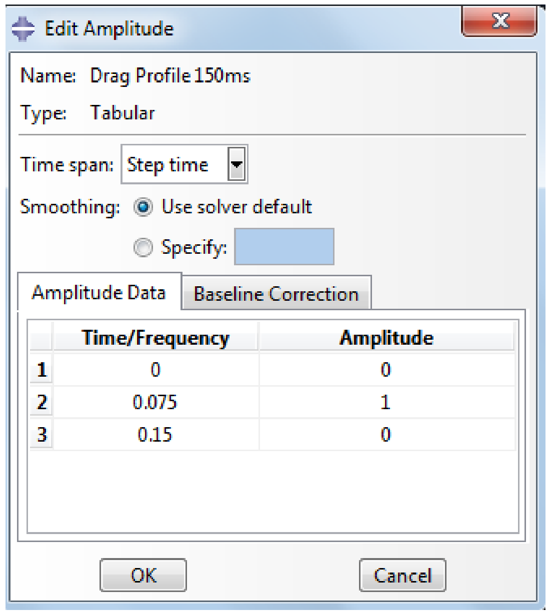


Figure 5-11 Biggs curve of a triangular symmetric pulse.

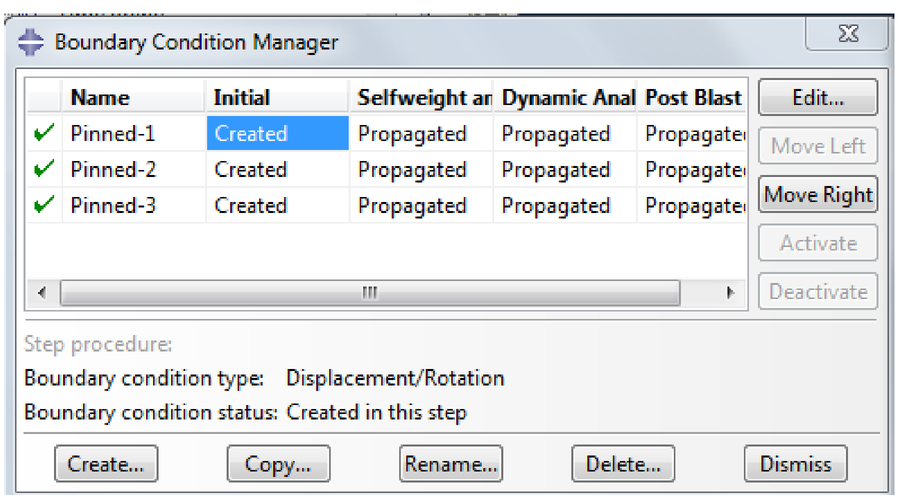


Figure 5-12 Pinned Boundary Conditions Applied in Abaqus

5.9.4 Post-blast

The "Post-blast" step is a step without any loads imposed on the structure, but with the structural self-weight (gravity load) and piping weight propagating from the previous steps. The purpose of this step is to study the post-blast response of the structure.

6.0 Static Analysis in STAAD PRO V8i

In order to perform static analyses of the pipe rack software Staad Pro has to be used.

This content of this chapter includes general geometry, boundary conditions (BCs), applying steel sections and loads. In Figure 6-1 the 3-D model of the pipe rack is illustrated.

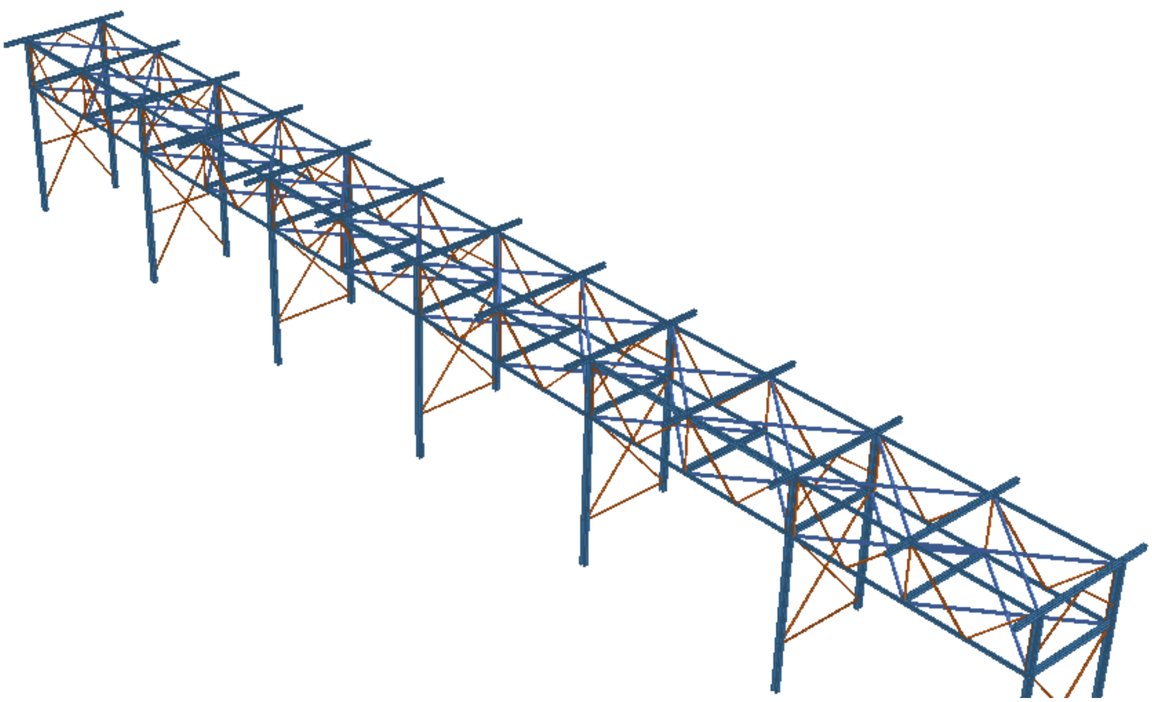


Figure 6-1 Three Dimensional (3-D) of Pipe Rack

6.1 Methodology

There are no Pipe rack models in Staad Pro for static analysis, however there is a way to create own geometry model. Default material property for Carbon steel is also available in software. Further different steel sections are available in the software library which will reduced the time for static analysis. The following scheme (Figure 6-2Figure 5-2) describes the modelling and calculating processes used for analysis of Pipe rack in the present study.

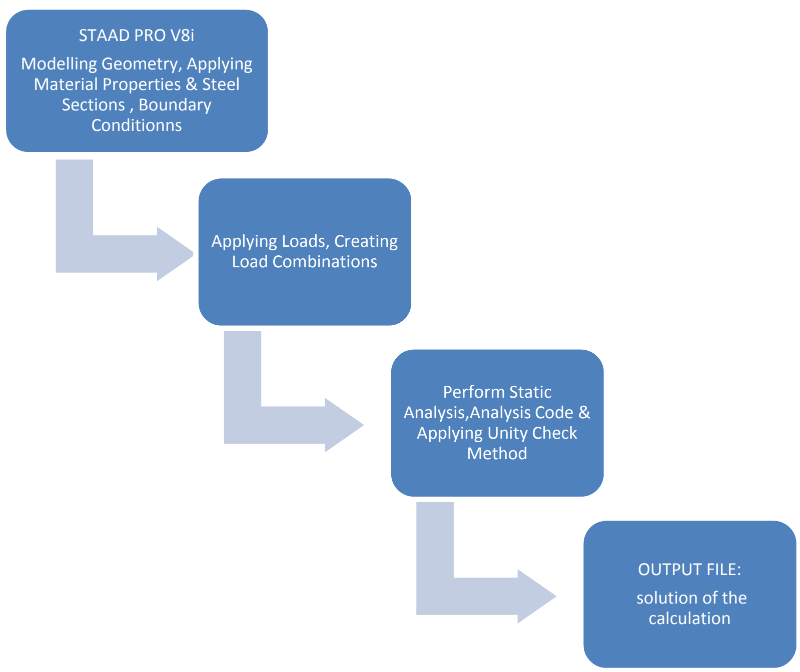


Figure 6-2 Methodology for Pipe Rack Analysis

6.2 Modeling of Geometry

In modelling of pipe rack staad pro has its modelling grid for easily modelling any structure in Staad Pro. Pipe rack structure has to be model as a beam elements. Following European sections are used:

- HEA-200
- HEA-240
- HEA-120
- Half IPE-200
- Angle 100x100x8
- Angle 50x50x8

Detail properties of these sections and angles are attached in Attachment-II.

6.3 Material settings

As we are doing static analysis of Pipe rack so plastic properties of steel material are not required. Further Staad select the default value of density and yield strength.

6.4 Boundary Conditions

For our pipe rack we considered pinned supports which means that the column is fixed in 3DOFs ($\sum Fx=\sum Fy=\sum Fz=0$) whereas the moments are considered to be free. An overview of the boundary conditions imposed to the model in Staad Pro is found in Figure 6-3.

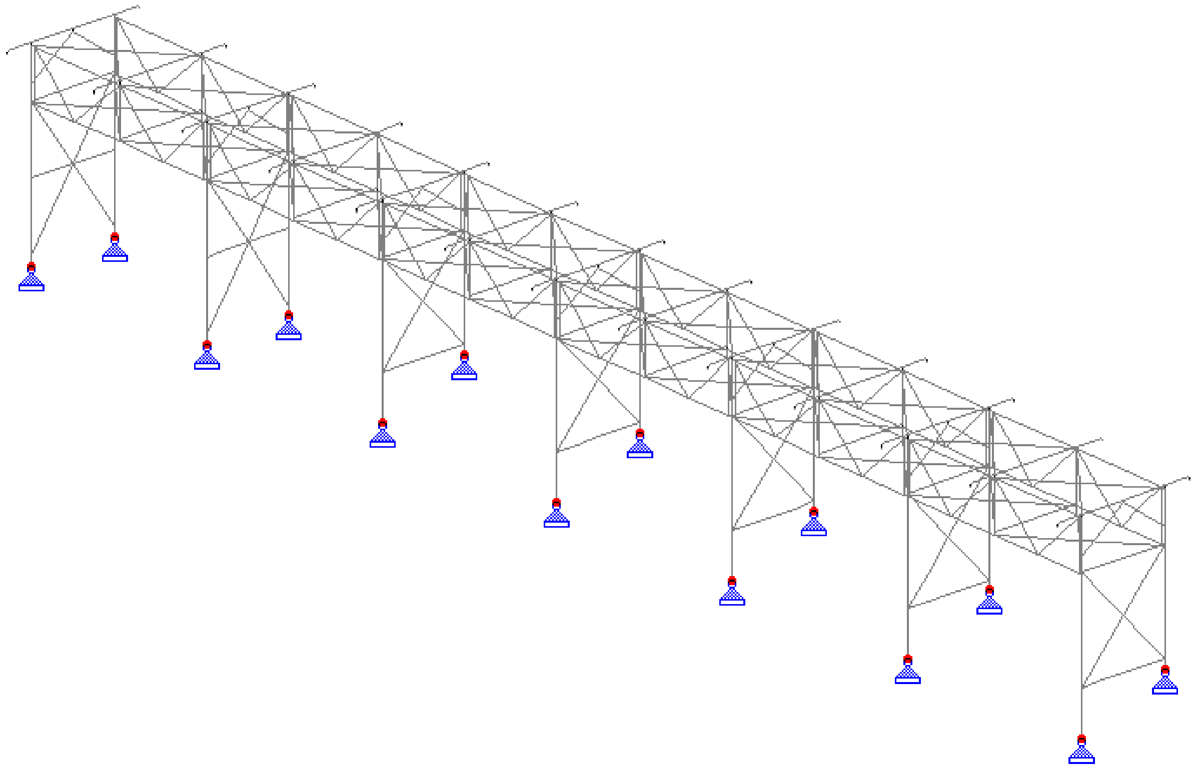


Figure 6-3Boundary Conditions of Pipe Rack

6.5 Selfweight of Strcture

The selfweight of structure in Staad Pro are applied as per software built in criteria and the factor of safety will be considered as unity.

6.6 Pipe Loads

The pipes loads are applied on Staad Pro for getting the static result of pipe rack. Three types of pipes load are applied which are as follows:

- Dead Load

- Live Load
- Friction Load

All these loads are briefly defined in section 2.3. Dead and Live loads are applied in –Y direction whereas friction loads are applied in longitudinal direction (opposite direction of flow). These loads are applied on the main beam of the pipe rack as shown in figure below

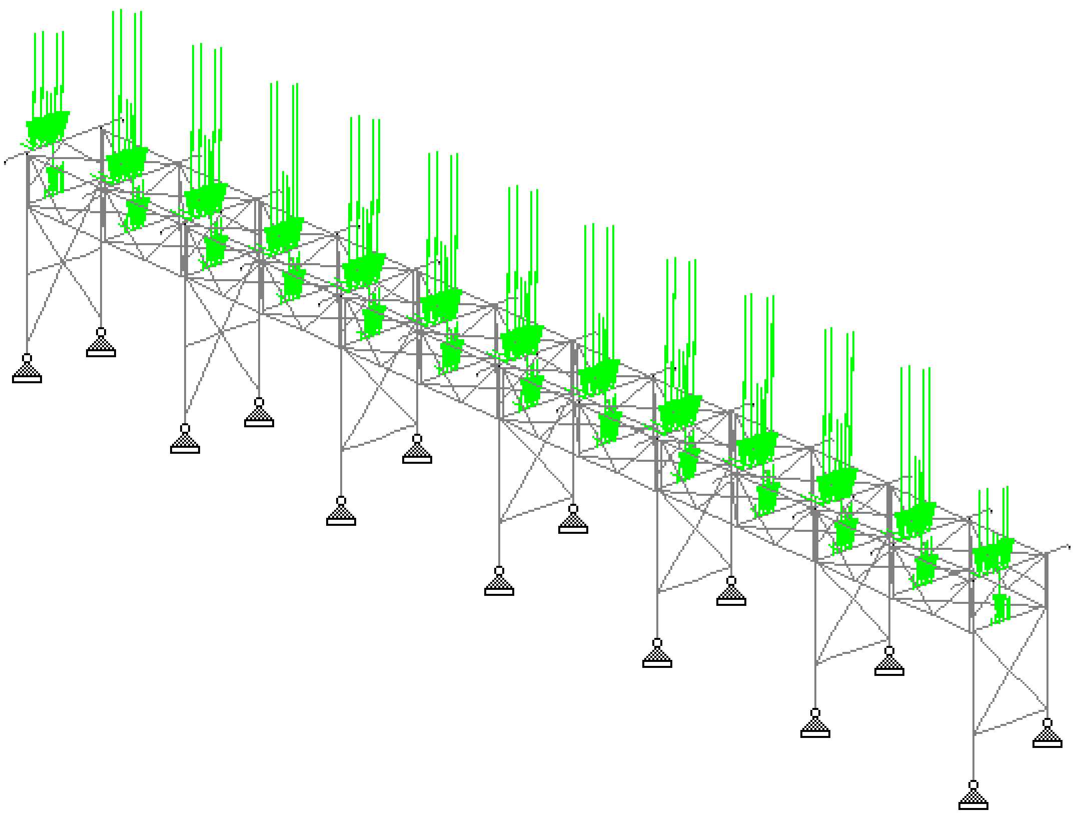


Figure 6-4 Dead, Live and Friction load

6.7 Wind Loads

Wind loads has been briefly discussed in section 2.3.10. By consider the design speed of 100mile/hr wind loads are calculated from ASCE equation. Wind loads are applied uniformly on the column as well as point load on the beam.

6.8 Earthquake Load

Staad Pro software has a built in calculation designed as per UBC Building structure code for checking the strength of structure if there is any vibration in the soil. For applying the earthquake load following parameters are considered:

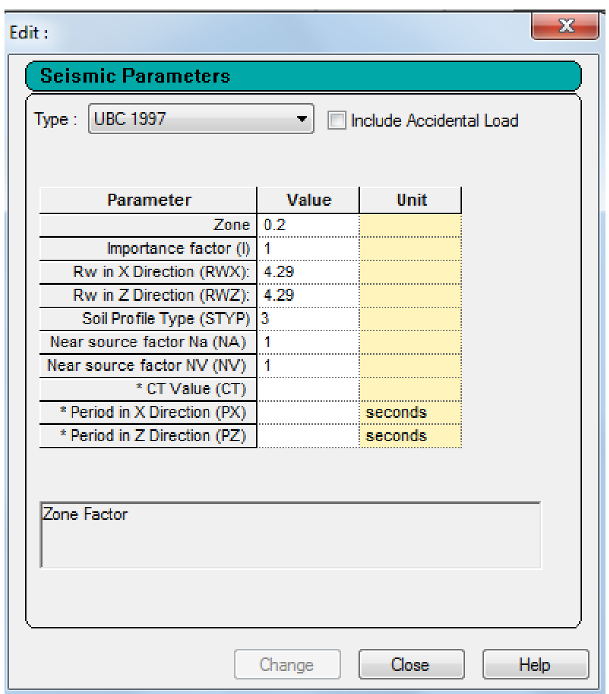


Figure 6-5 Earthquake Parameters Required In Staad Pro

6.9 Load Combinations For Static Analysis

For performing the static analysis of Pipe rack and check the unity ratio, displacements, Tensile and Compressive Stresses and reaction forces we have analyzed the piperack in advanced structural analysis software STAAD-PRO V8i, detail analysis has been performed on the pipe rack and all the primary loads has been applied.

The load combinations for the static analysis of Pipe Rack are as follows:

$D_L + L_L + F_f + A_F$ (if any)	***Load Comb. 1*** *(Max. Operating Gravity Loads)*
$0.75(0.9\ D_L + W_L)$	***Load Comb. 2*** *(Min. Dead Load + Wind)*
$0.75[D + L_L + AF + W_L$ or E(+xdirection)]	***Load Comb. 3a*** *(Max. Oper. Gravity + W or E)*
$0.75[D + L_L + AF + W_L$ or E(-xdirection)]	***Load Comb. 3b*** *(Max. Oper. Gravity + W or E)*
$0.75[D + L_L + AF + W_L$ or E(+zdirection)]	***Load Comb. 3c*** *(Max. Oper. Gravity + W or E)*
$0.75[D + L_L + AF + W_L$ or E(-zdirection)]	***Load Comb. 3d*** *(Max. Oper. Gravity + W or E)*

7.0 Analysis Results

This chapter discussed the results performed on the pipe rack using both the static and dynamic model. A majority discussion will be done for study the behavior of structure during blast by comparing static and dynamic analysis models. Dynamic Amplification factor has been calculated by considering the reaction forces of supports for static and dynamic analysis models which gives understanding of how pipe rack responds to blast loads. The structural response will be described in terms of deflection (mm) and reaction forces (kN). The DAF is the ratio of dynamic parameter (deflection, reaction forces and Stresses etc.) to static parameter (deflection, reaction forces and Stresses etc.)

A study has been done on pipe rack and followings are the parameter considered:

- Blast load duration, T_d: 50, 100, 150 and 200 ms
- Blast load drag pressure level, P_d: 0.2 bar and 0.4 bar
- Structure and piping weight

7.1 Dynamic Amplification Factors (DAF)

The DAF is conventionally defined as the ratio between the dynamic deflection at any time to the deflection which would have resulted from the static application of the load as defined in Equation 2.1 (Biggs, 1964) [35]. You can also considered reaction forces, stress etc for calculating the DAF.

$$DAF = \frac{R_{dyn}}{R_{static}}$$ *Equation 7-1*

A larger effect has been seen on the structure as compare to static analysis if dynamic analysis is calculated. This is applicable for structural responses due to blast loads. The DAF reflects the increase of response due to a dynamic load.

7.2 Verifying the StructureModelled in Abaqus

Before starting the dynamic analysis of the pipe rack in abaqus it is required to check the geometry, material properties and steel sections that has been modeled on abaqus. In this respect we have applied the static check of pipe rack in both software (Staad Pro and Abaqus). For verifying the above perimeters only self weight load of the structure has been applied on both software and reaction forces on the supports of the column has been check. The results are as follows:

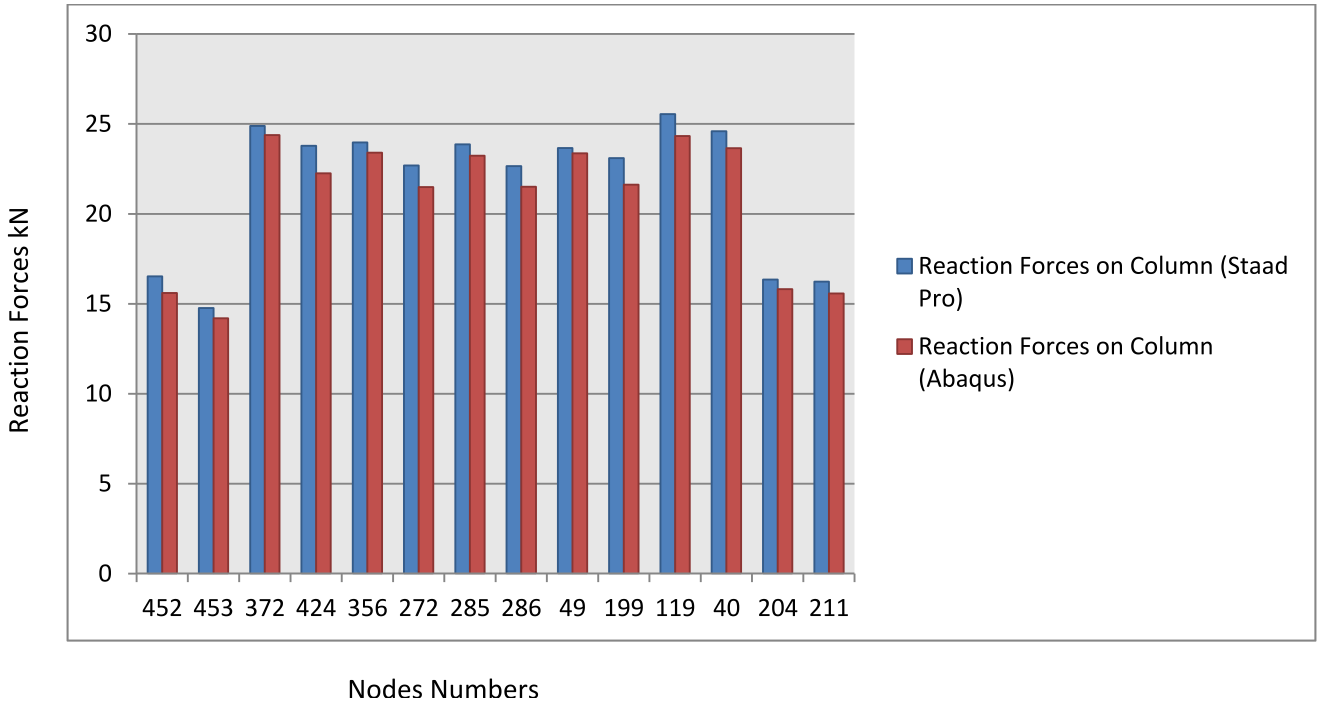


Figure 7-1 Reaction Forces on Columns

After reviewing the reaction forces that has been calculated from both the software it is clearly seen that the reaction forces are varying 5% which is acceptable as both software work on different solution basis.

7.3 Static Results

Static analyses have been performed with the purpose of studying the static structural response for the simplified analysis model.The difference between dynamic and static analysis depends on the loads that has to be applied on the structure. In static analysis the loads are static i.e. time independent, while dynamic load are time dependent. A static load is applied with constant amplitude while the dynamic load can be start from zero and built up to reach its highest value and subsequently decrease, e.g. a load expressed as a symmetric triangular pulse. During the static analysis of pipe rack following perimeters are check.

7.4 Utilization of structural steel

Please refer to Attachment-4 where Utilization Ratio of all the steel members has been checked and design optimization has also been performed on the steel members which has low value of unity ratio.

7.5 Deflection in Structural Steel

The deflection should be higher on the top node of the column because of the loads acting on the transverse beam; therefore, displacements have been check from the software and refer to Attachment-5 the displacements on the column are below H/150. Hence all the displacements on the steel section are acceptable. The reaction forces have been obtained in the analysis which shall be used in the blast analysis of pipe rack.

7.6 Stress (Von-Mises)

In dynamic analyses it clearly shows from Figure 7-2 to Figure 7-17 that the stress variations on the structure are within the material's elastic range. It is observed from results that the maximum response amplitude, e.g Von-Mises stresses are higher during the post-blast step than under the blast step.

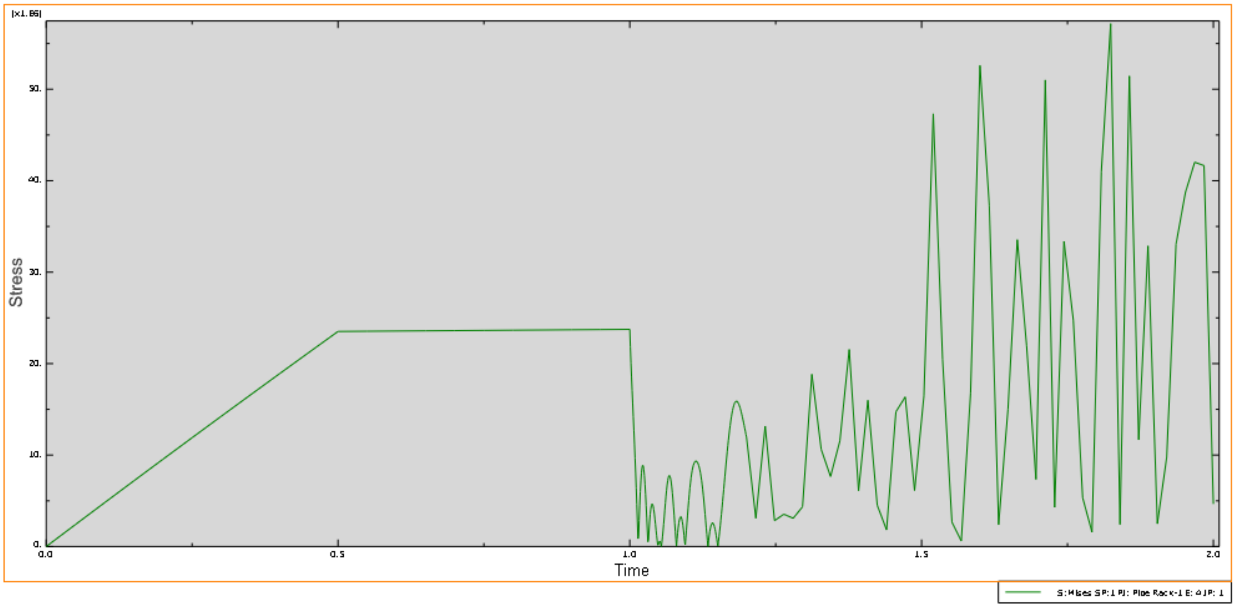


Figure 7-2 Dynamic response with respect to Von-Mises stresses (200ms,0.2bar) on Transverse Beams with Piping Arrangement.

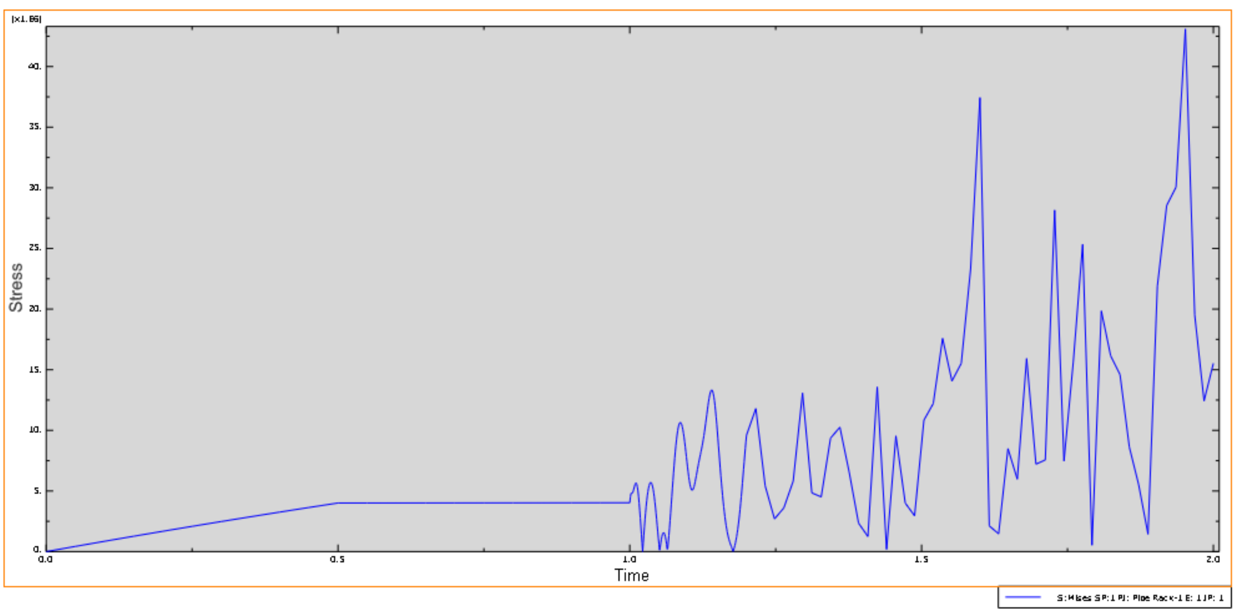


Figure 7-3 Dynamic response with respect to Von-Mises stresses (200ms,0.2bar) on Transverse Beams with only Self weight of Structure.

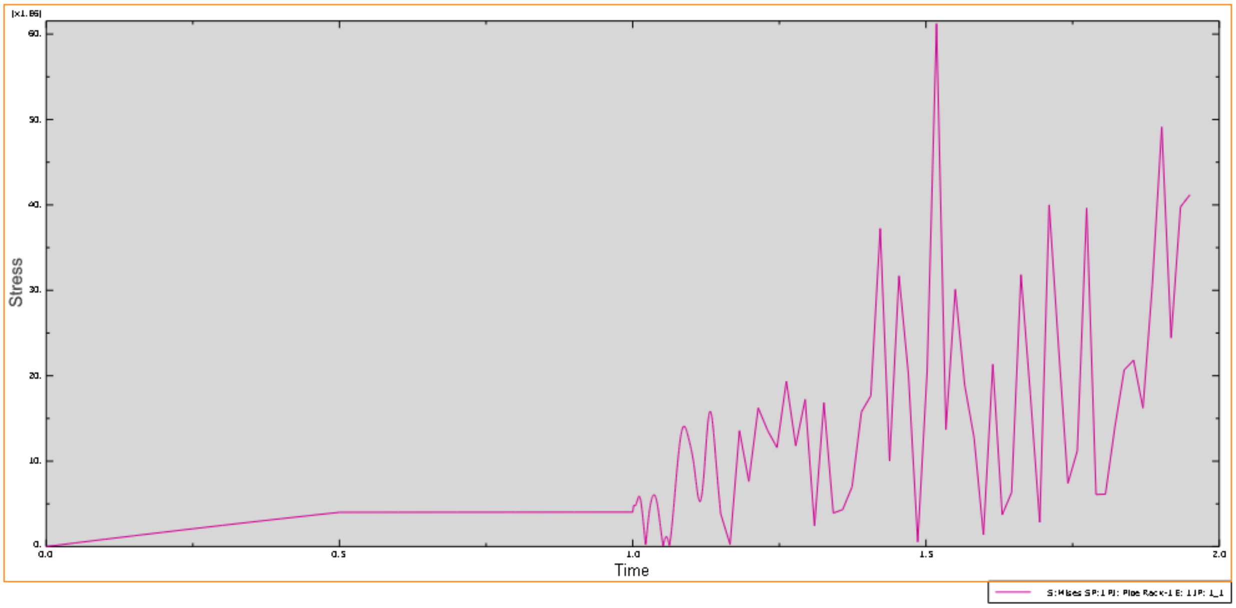


Figure 7-4 Dynamic response with respect to Von-Mises stresses (150ms,0.2bar) on Transverse Beams with Piping Arrangement.

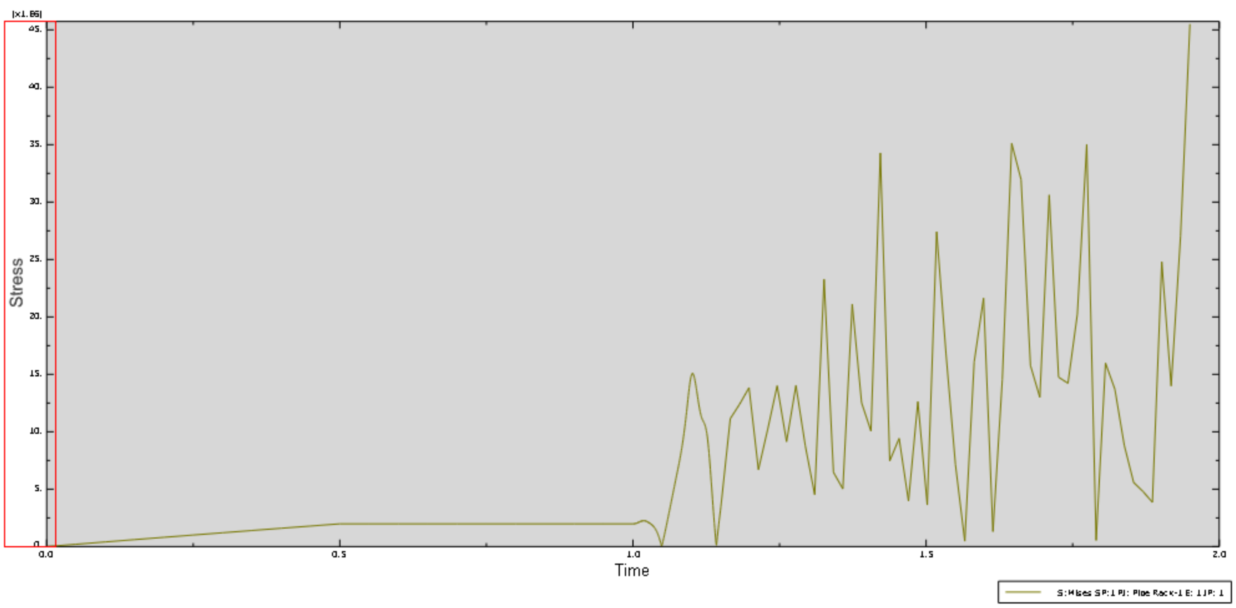


Figure 7-5 Dynamic response with respect to Von-Mises stresses (150ms,0.2bar) on Transverse Beams with only Self weight of Structure

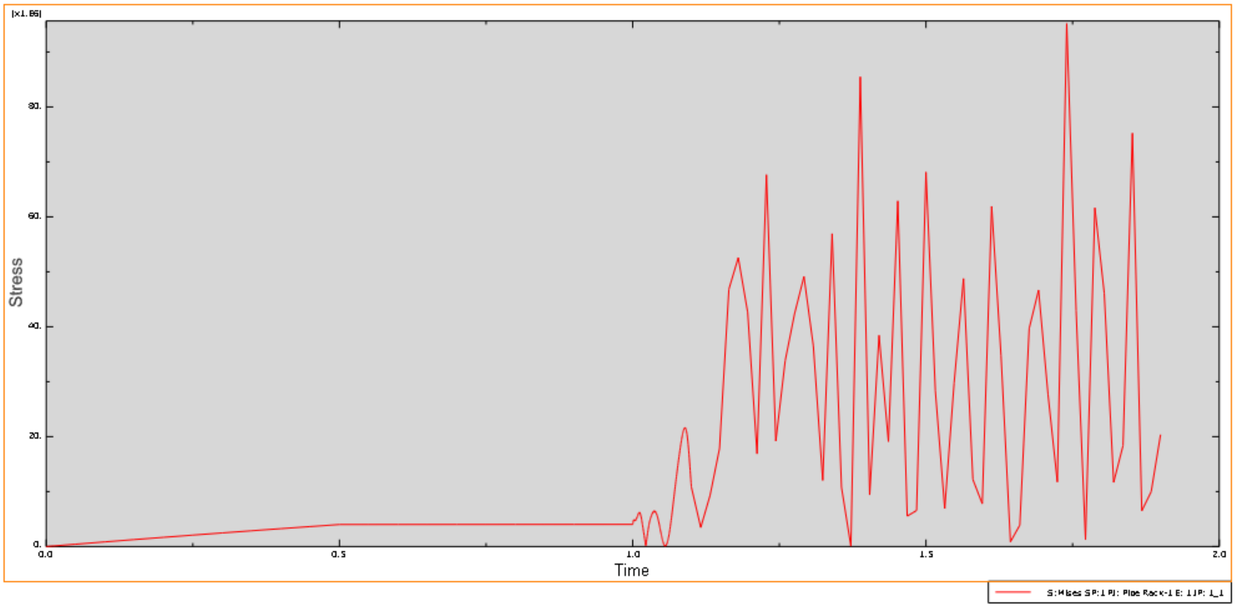


Figure 7-6 Dynamic response with respect to Von-Mises stresses (100ms,0.2bar) on Transverse Beams with Piping Arrangement.

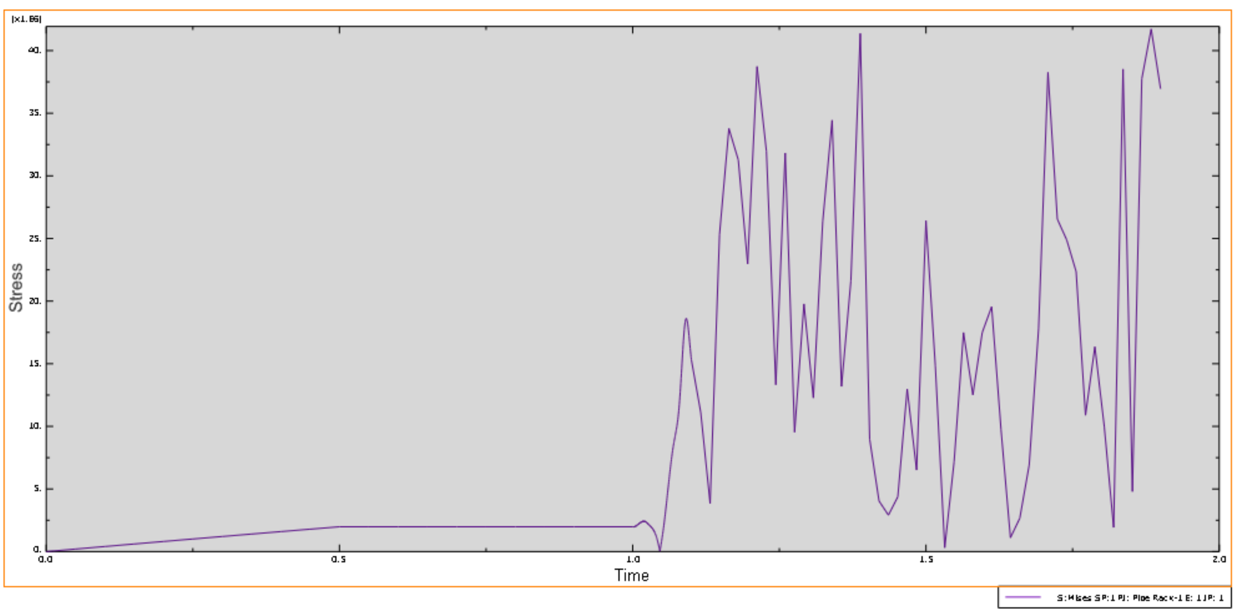


Figure 7-7 Dynamic response with respect to Von-Mises stresses (100ms,0.2bar) on Transverse Beams with only Self weight of Structure

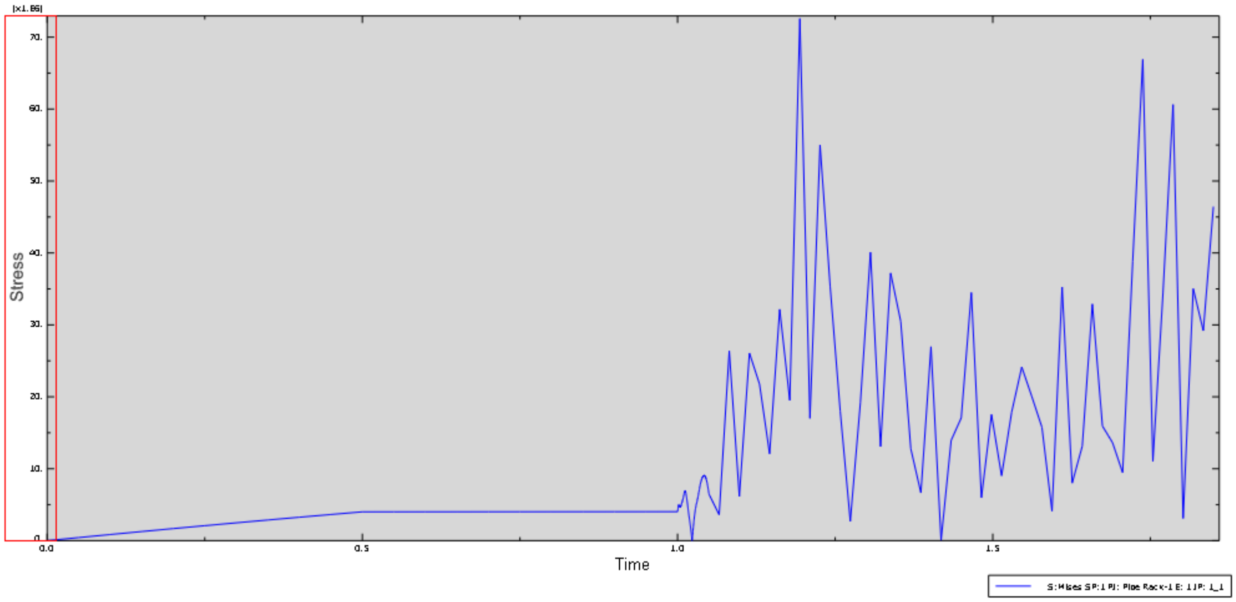


Figure 7-8: Dynamic response with respect to Von-Mises stresses (50ms,0.2bar) on Transverse Beams with Piping Arrangement.

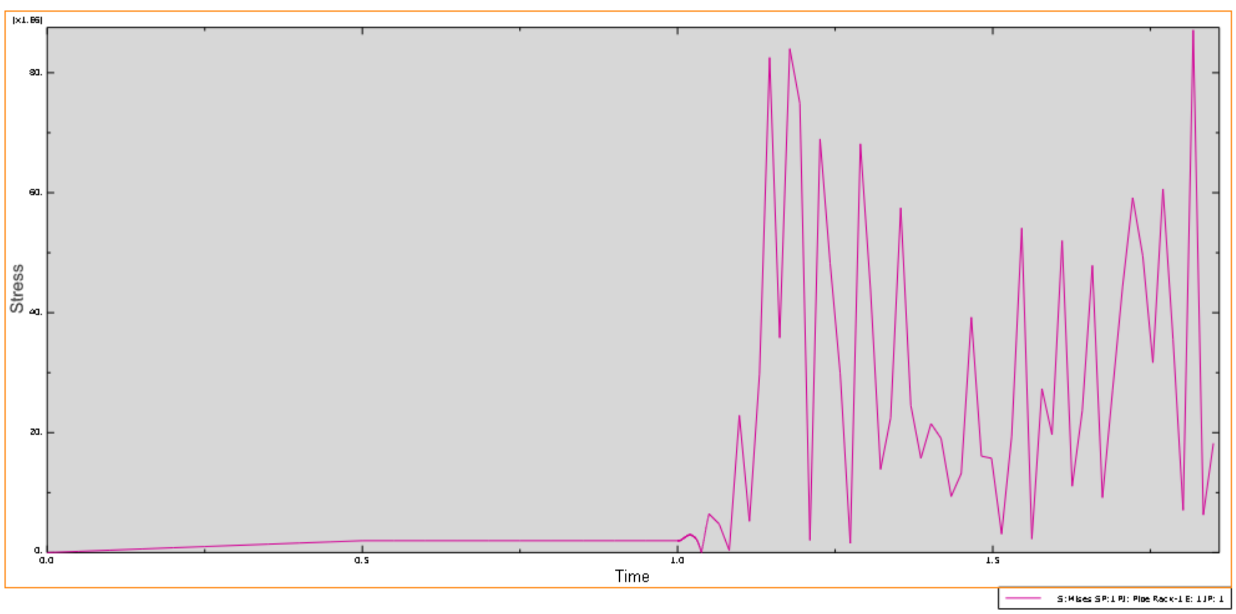
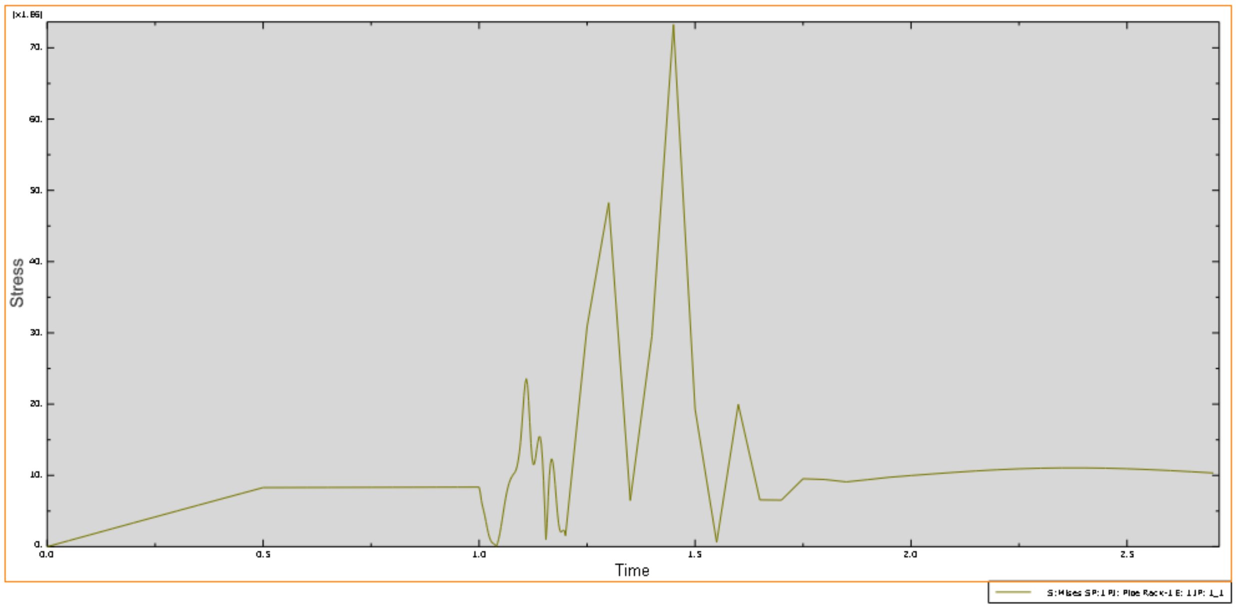
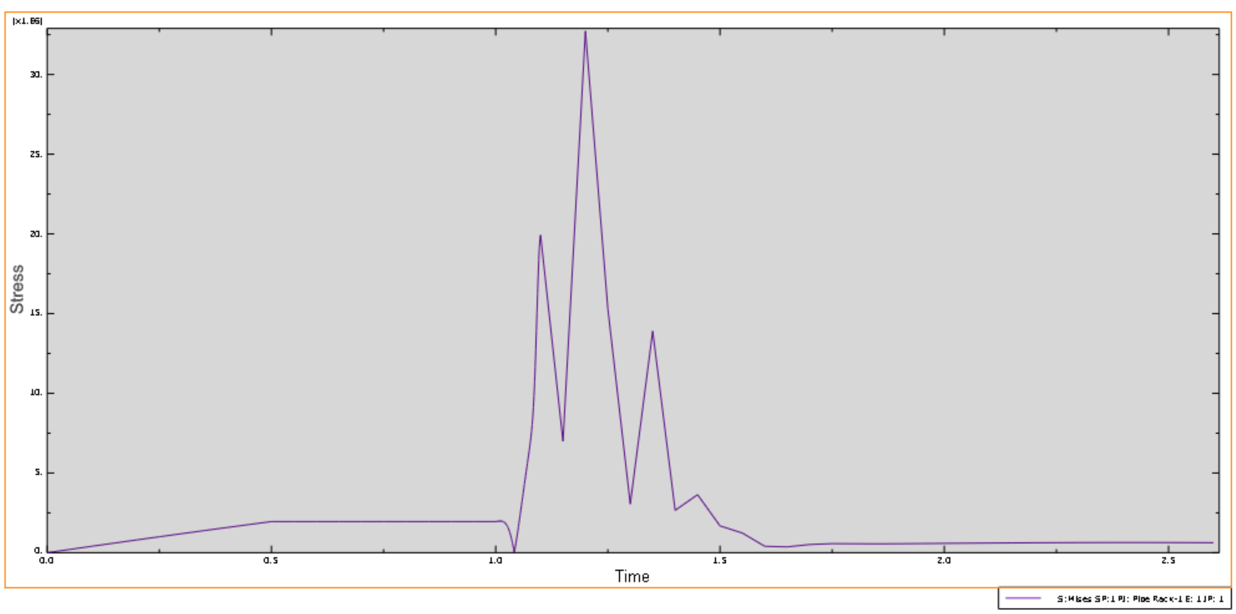


Figure 7-9 Dynamic response with respect to Von-Mises stresses (50ms,0.2bar) on Transverse Beams with only Self weight of Structure



<u>Figure 7-10 Dynamic response with respect to Von-Mises stresses (200ms,0.4 bar) on Transverse Beams with Piping Arrangement.</u>



<u>Figure 7-11 Dynamic response with respect to Von-Mises stresses (200ms,0.4 bar) on Transverse Beams with only Self weight of Structure</u>

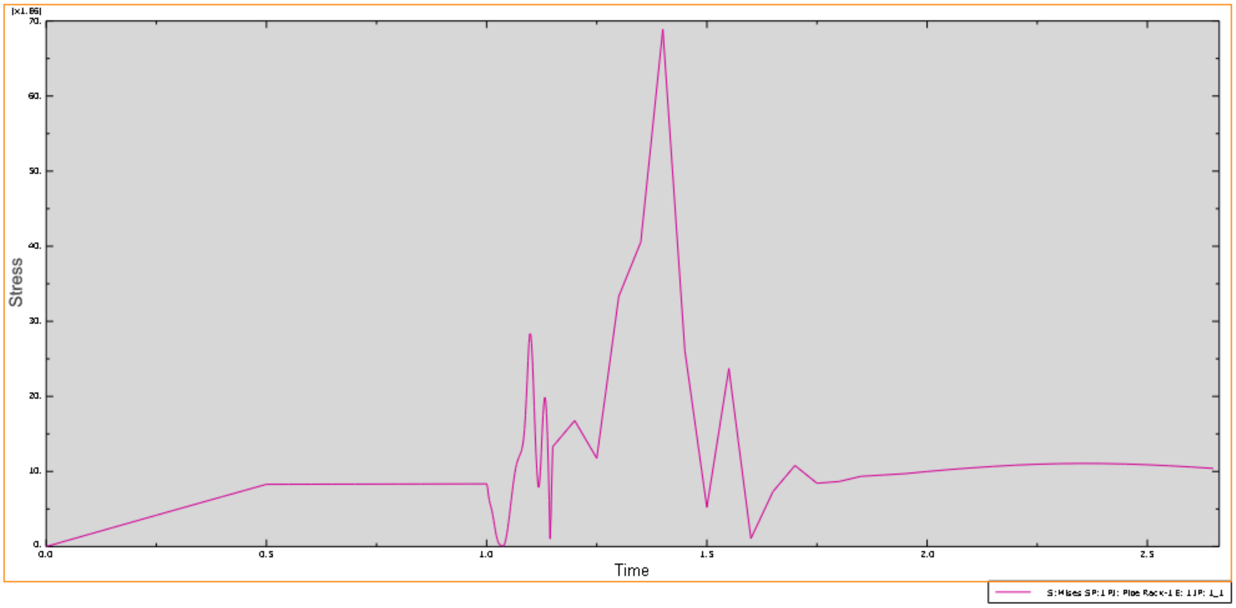


Figure 7-12 Dynamic response with respect to Von-Mises stresses (150ms,0.4 bar) on Transverse Beams with Piping Arrangement

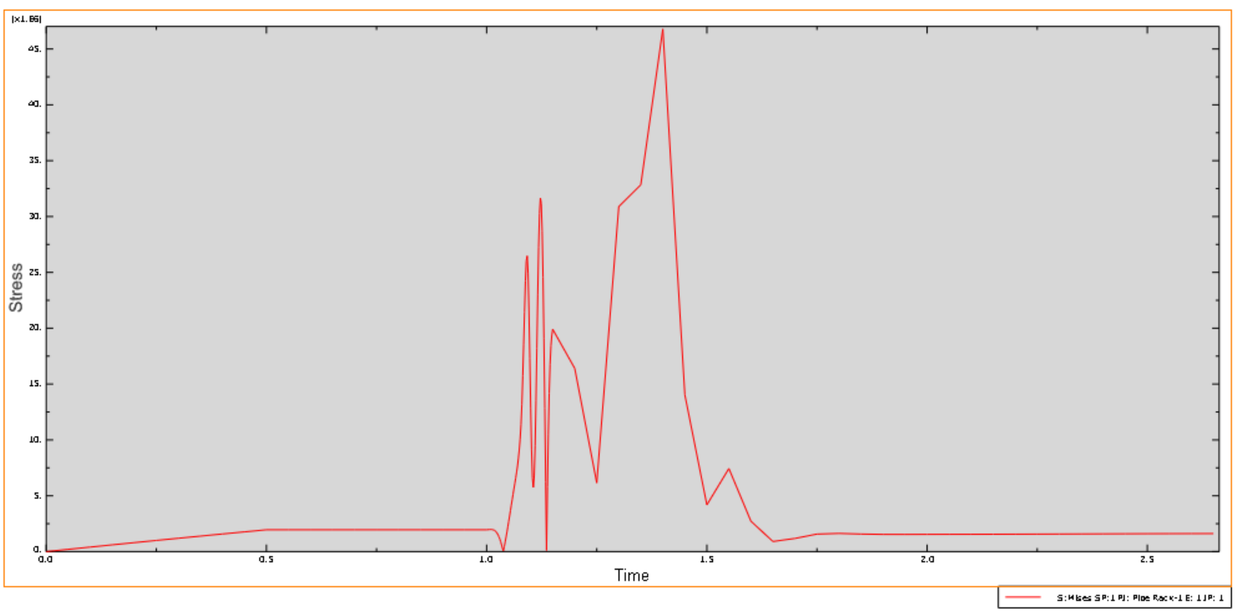
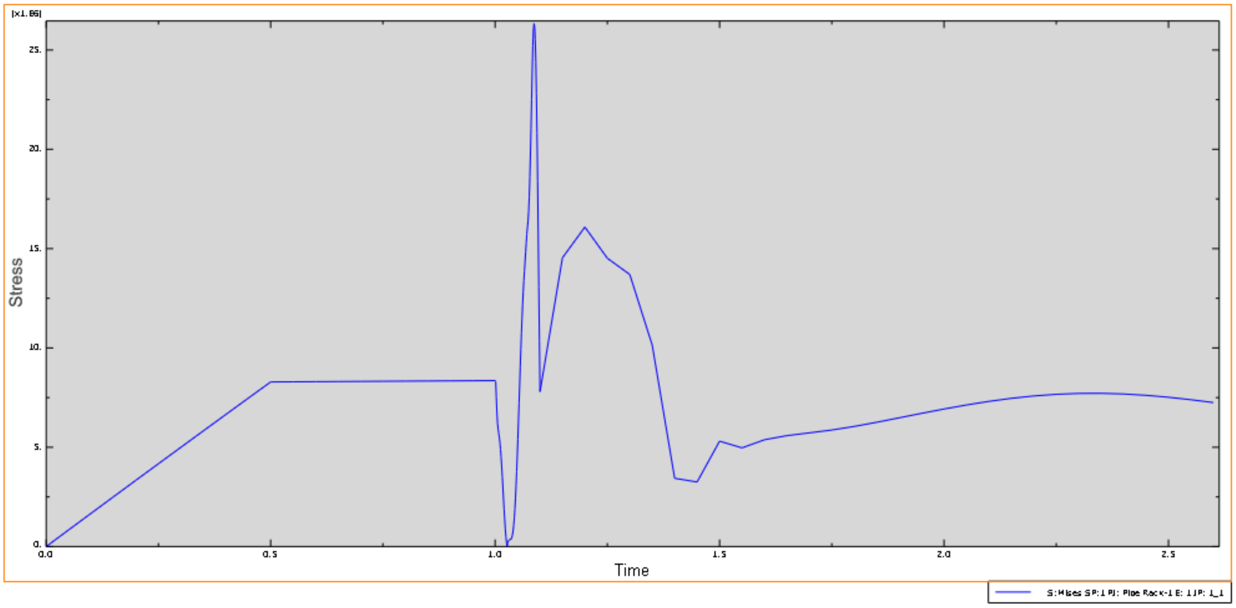
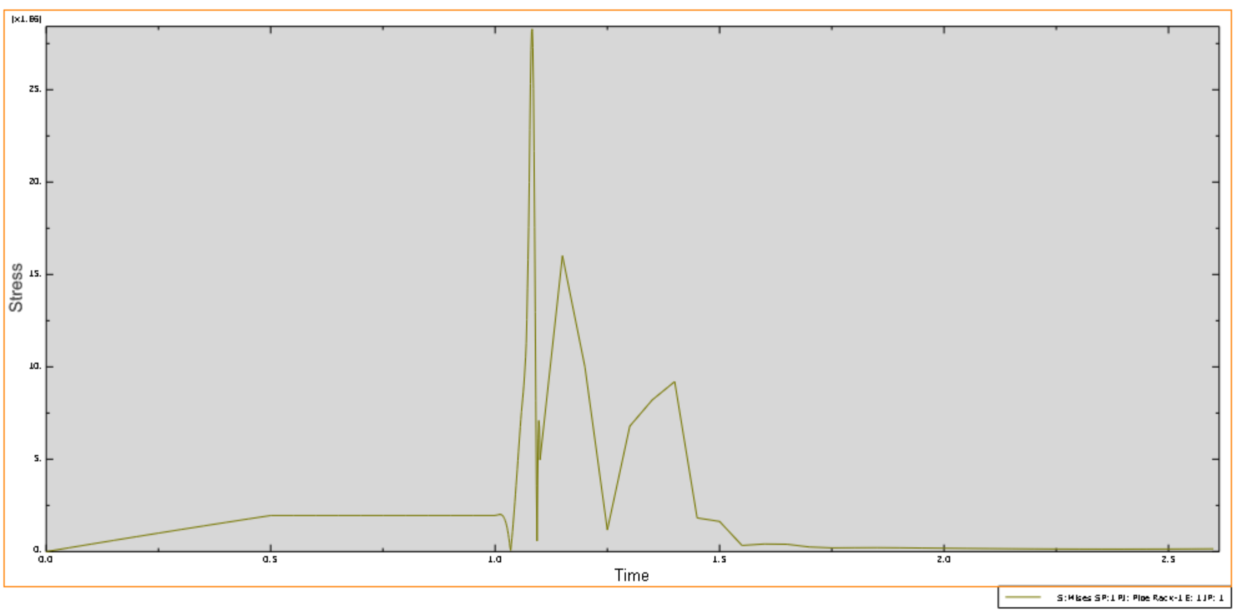


Figure 7-13 Dynamic response with respect to Von-Mises stresses (150ms,0.4 bar) on Transverse Beams with only Self weight of Structure



<u>Figure 7-14 Dynamic response with respect to Von-Mises stresses (100ms,0.4 bar) on Transverse Beams with Piping Arrangement.</u>



<u>Figure 7-15 Dynamic response with respect to Von-Mises stresses (100ms,0.4 bar) on Transverse Beams with only Self weight of Structure</u>

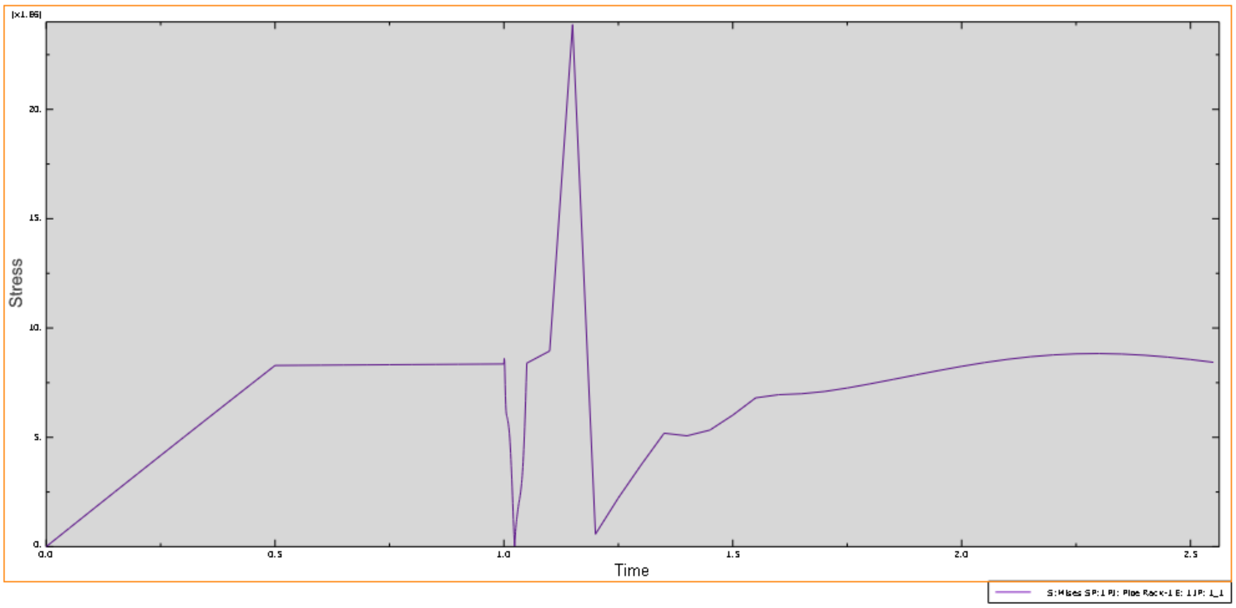


Figure 7-16: Dynamic response with respect to Von-Mises stresses (50ms,0.4 bar) on Transverse Beams with Piping Arrangement.

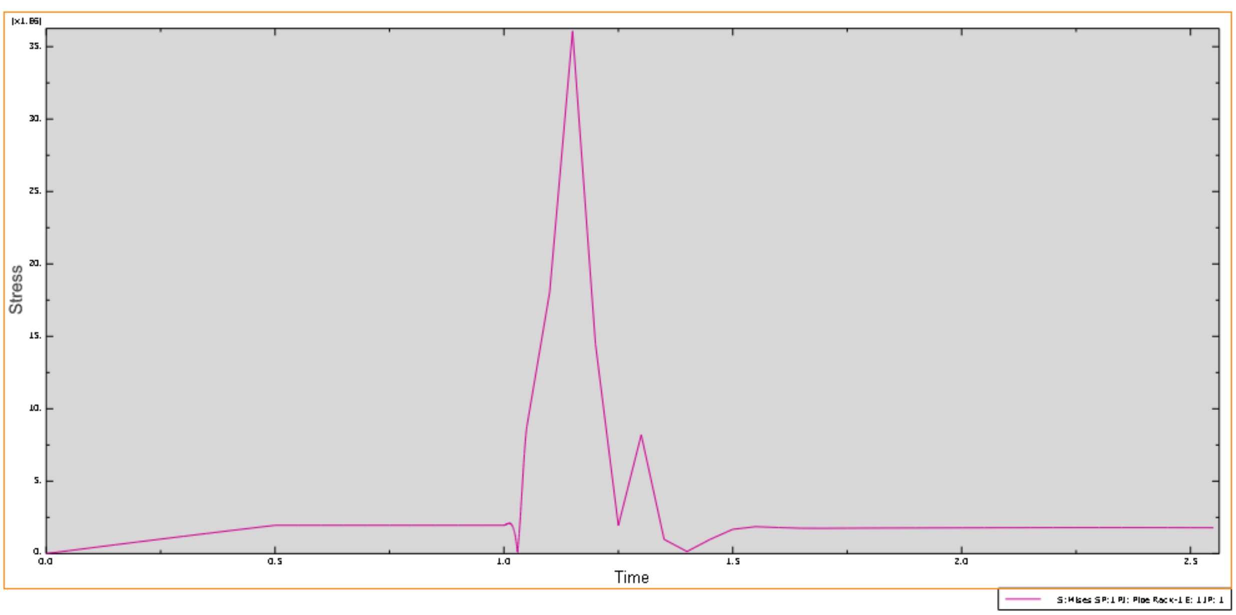


Figure 7-17 Dynamic response with respect to Von-Mises stresses (50ms,0.4 bar) on Transverse Beams with only Self weight of Structure

7.7 Reaction Forces (Support Reactions) and Displacements Calculation for DAF

Dynamic amplification factors (DAFs) are to be calculated for all support reactions (end connections in the model). The support reaction forces can be found by take out the nodal reaction forces (RF-forces) in the X, Y and Z-direction. There are total 14 end connections in the model, Figure 7-18 shows the location and node numbering for these.

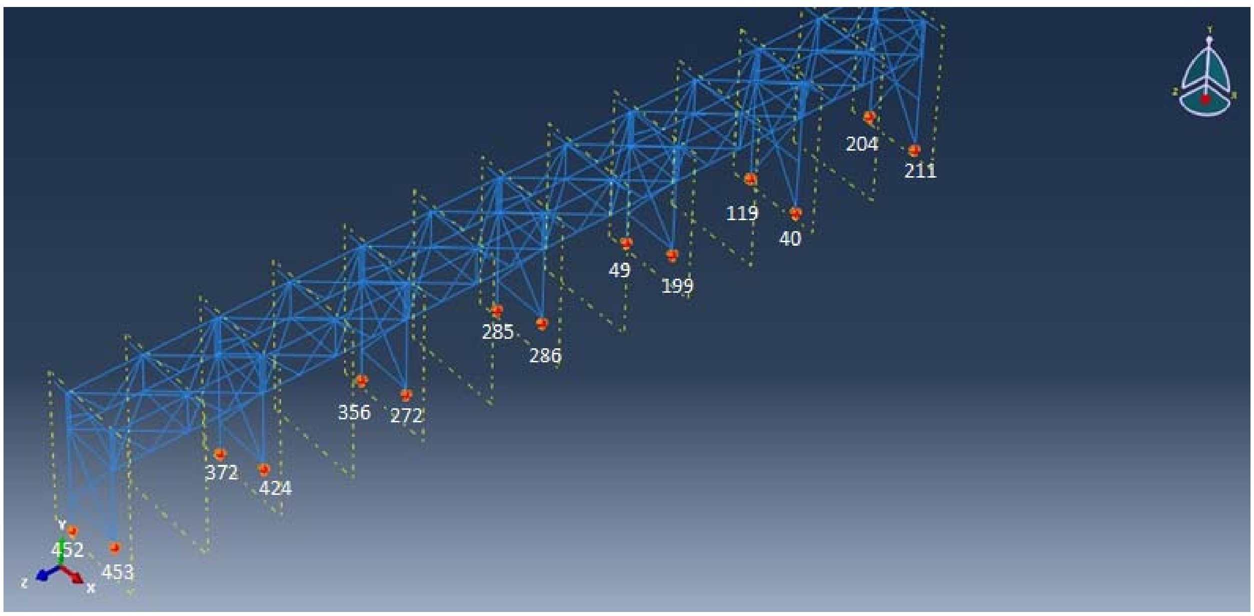


Figure 7-18 Reaction Forces in Nodes Numbers

The DAF is calculated between the dynamic and the static model. The reaction force has been investigated in the blast step.

Reaction forces in the Y- and X-directions (RF2 and RF1) is of most importance, as these two forces represent the support reactions in the direction of the gravity and blast respectively where the reaction force in Z-direction is negligible.

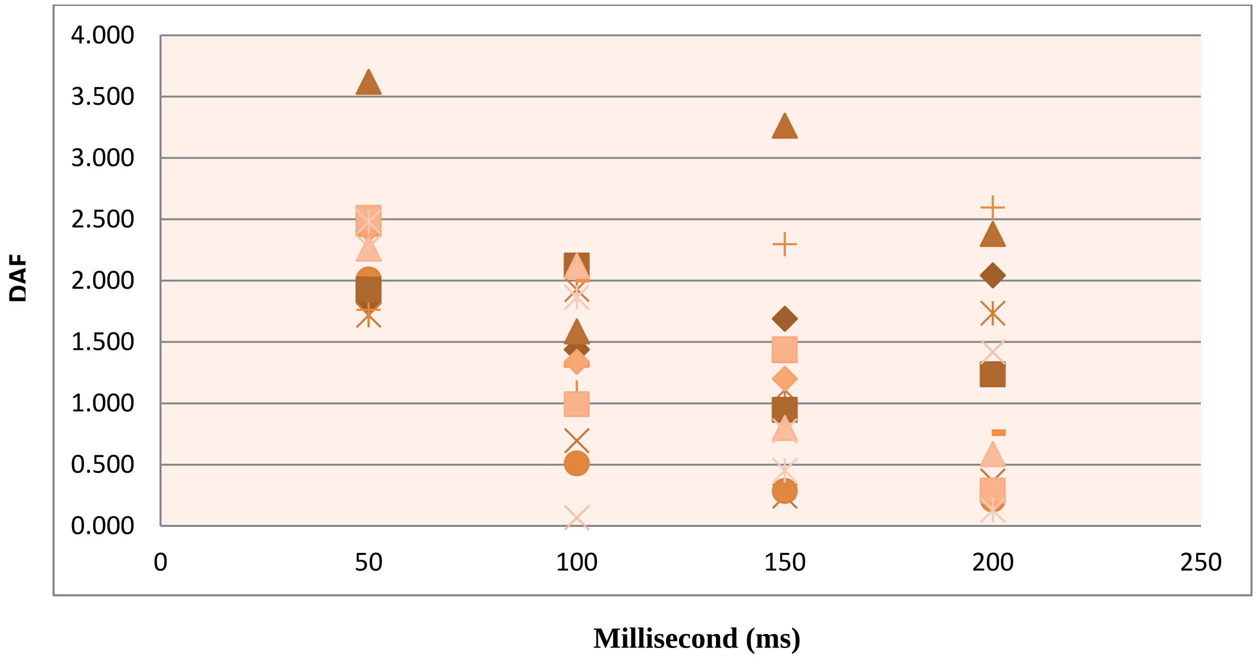


Figure 7-19 DAF vs Blast Duration for Dynamic Analysis Step (Reaction Force in X-direction) for 0.4 bar with Piping and Self weight Arrangement

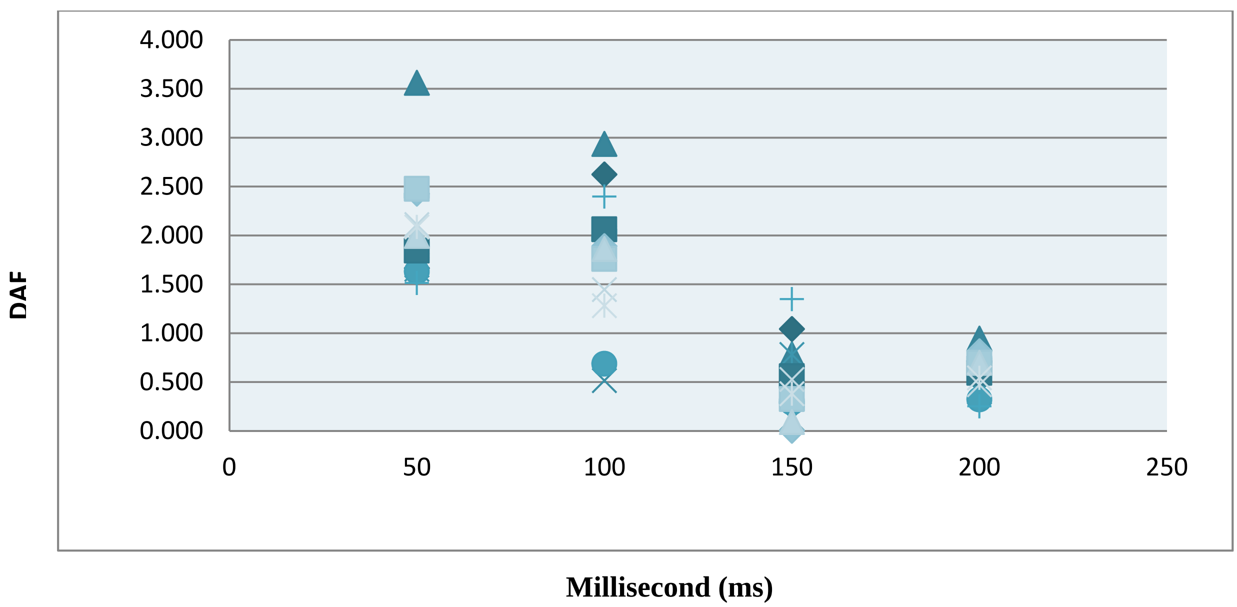


Figure 7-20 DAF vs Blast Duration for Dynamic Analysis Step (Reaction Force in X-direction) for 0.2 bar with Piping and Self weight Arrangement

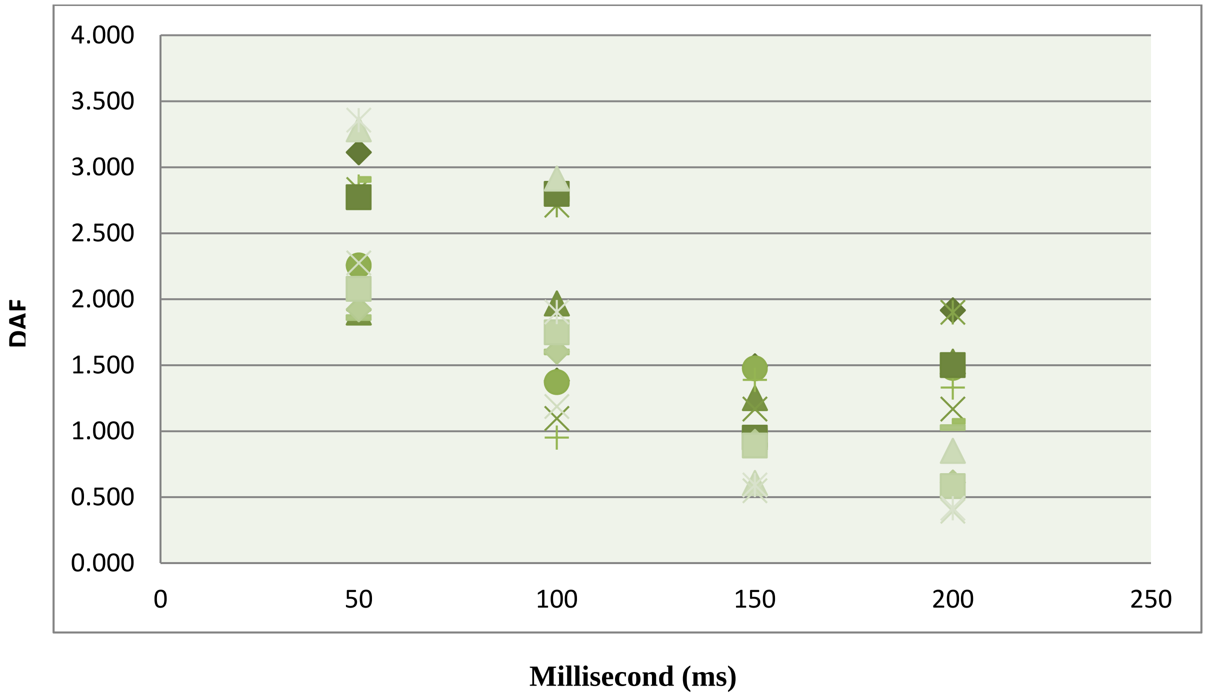


Figure 7-21 DAF vs Blast Duration for Dynamic Analysis Step (Reaction Force in Y-direction) for 0.4 bar with Piping and Self weight Arrangement

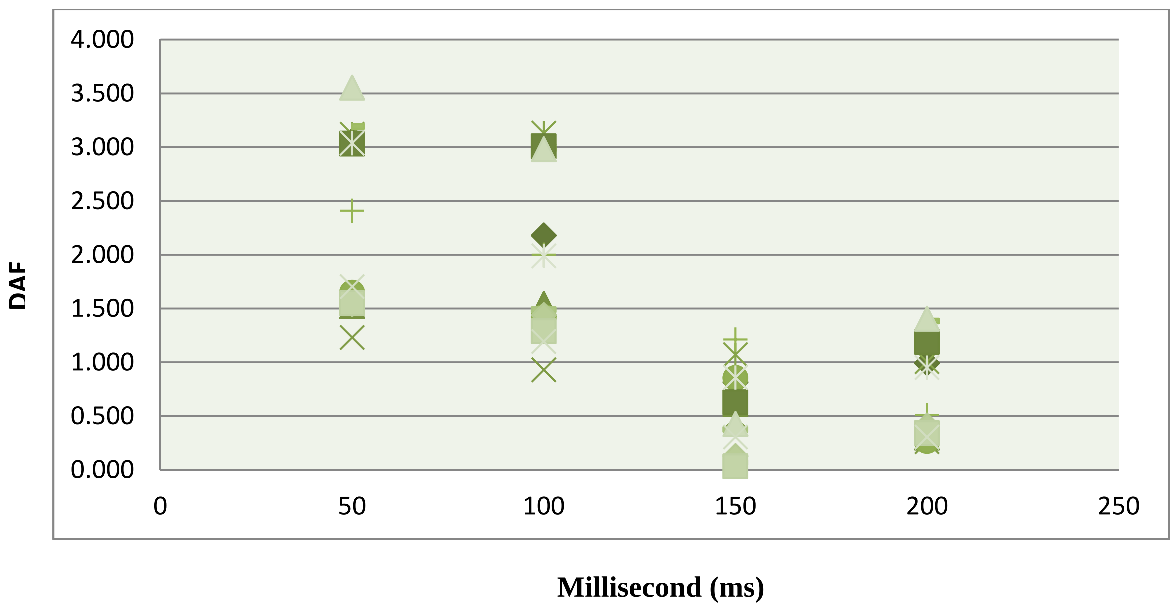


Figure 7-22 DAF vs Blast Duration for Dynamic Analysis Step (Reaction Force in Y-direction) for 0.2 bar with Piping and Self weight Arrangement

It is observed from Figure 7-19 to Figure 7-22 that DAF for 50ms will be high in all nodes among all blast duration.

Dynamic amplification factors (DAFs) are to be calculated from the displacements result of the nodes of the structure. The nodes displacements can be found by take out the nodal resultant displacements. There are total 16 nodes selected from random area of pipe rack in the model, Figure 7-23 shows the location and node numbering for these.

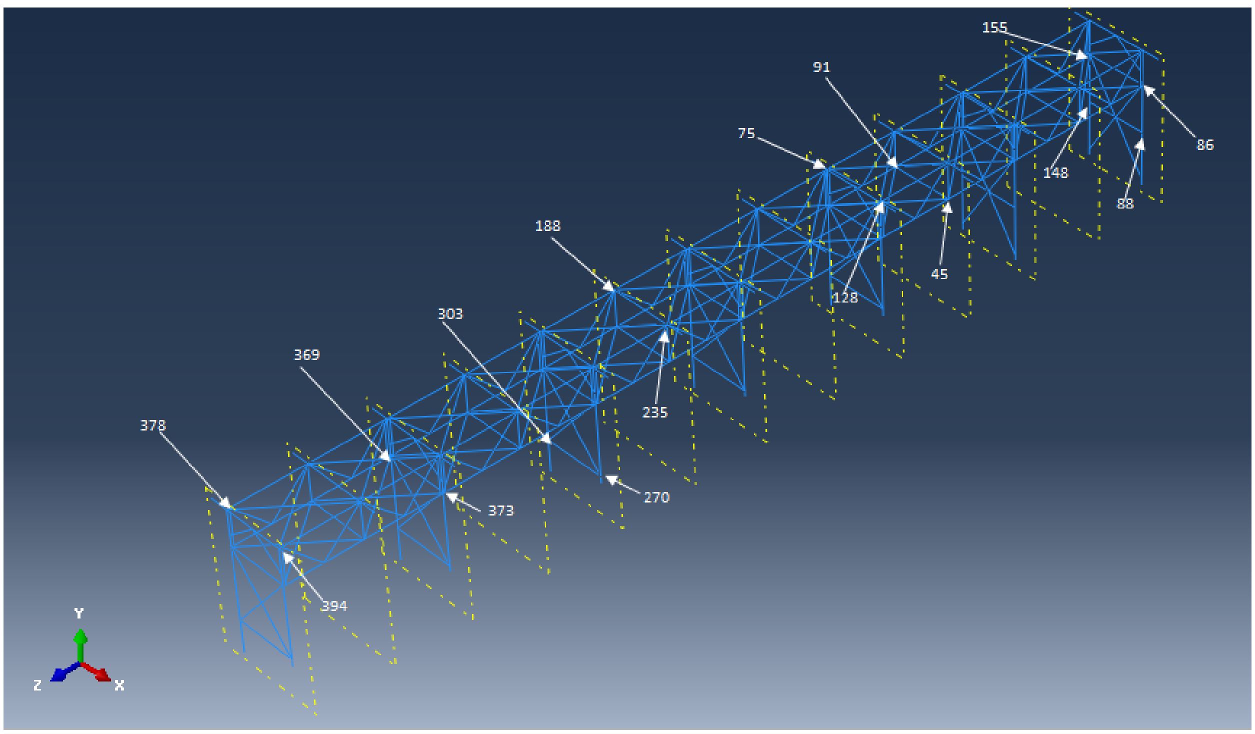


Figure 7-23 Nodes Numbers which displacements are calculated

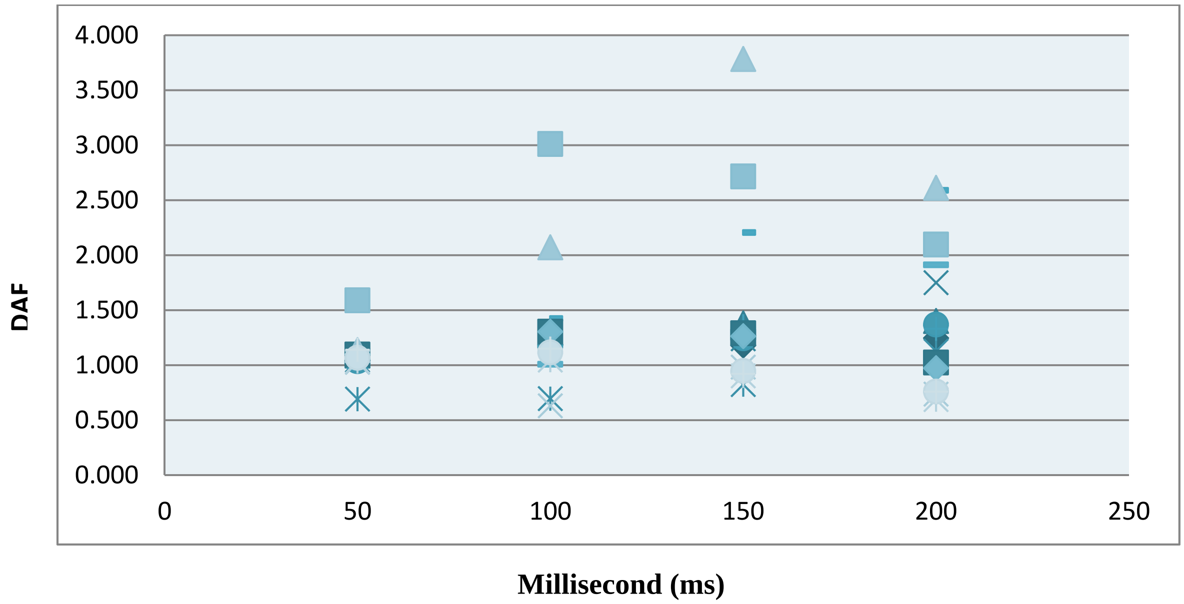


Figure 7-24 DAF vs Blast Duration for Dynamic Analysis Step (nodal displacements) for 0.4 bar with Piping and Self weight Arrangement

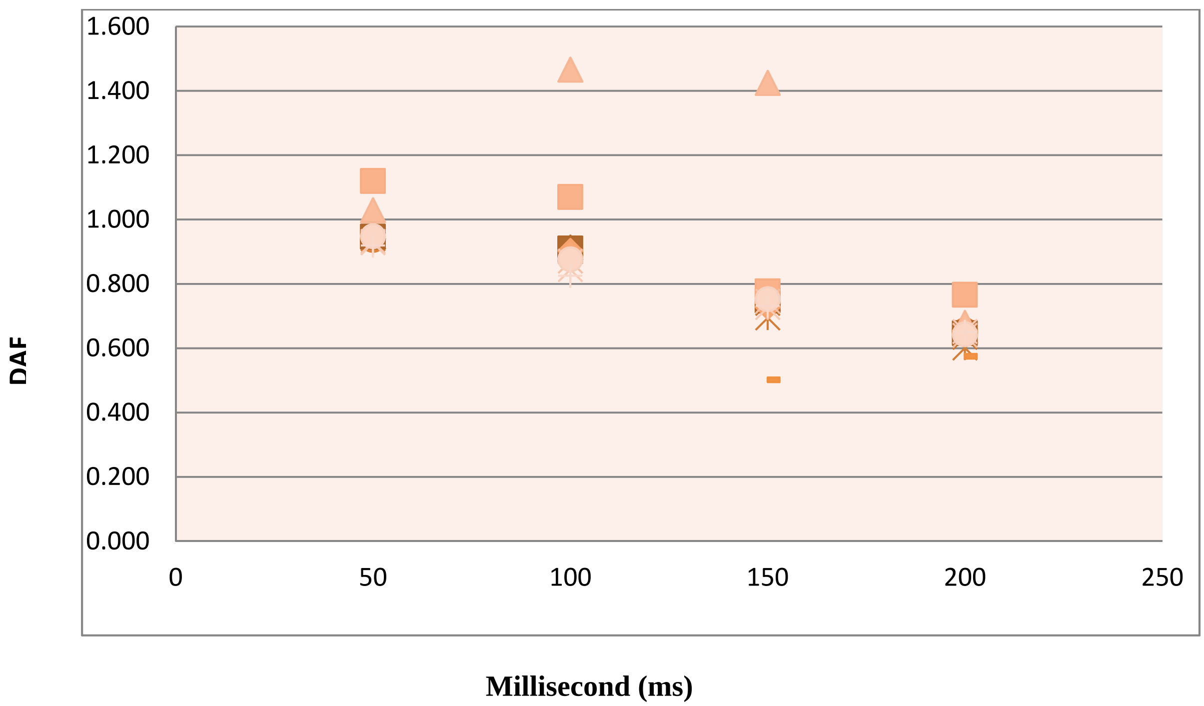


Figure 7-25 DAF vs Blast Duration for Dynamic Analysis Step (nodal displacements) for 0.2 bar with Piping and Self weight Arrangement

As we have selected random nodes for calculation DAF in terms of displacements from different points of pipe rack so neglecting some nodes that are moving irregular in different blast duration (ms) it is observed that for 0.4 bar pressure load the DAF will increases in all blast duration however for 0.2 bar pressure load the DAF decreases with the increase in blast duration.

7.8 Summary

Table 7-1 DAF (Dynamic Amplification Factor) for Blast Duration from Reaction Forces for 0.2 and 0.4 Bar

Blast Duration	DAF (0.2 bar Pressure Load)			DAF DAF (0.4 bar Pressure Load)		
	Fx	Fy	DAF	Fx	Fy	DAF
50ms	2.476	3.193	3.193	2.481	3.358	3.358
100ms	2.624	3.132	3.132	2.263	3.289	3.289
150ms	1.349	1.215	1.349	2.299	1.476	2.299
200ms	0.814	1.408	1.408	2.597	1.901	2.597

Table 7-2 DAF (Dynamic Amplification Factor) for Blast Duration from Nodes Displacements for 0.2 and 0.4 Bar

Blast Duration	DAF (0.2 bar Pressure Load)	DAF (0.4 bar Pressure Load)
	DAF	DAF
50ms	1.120	1.142
100ms	1.071	1.426
150ms	0.777	2.207
200ms	0.767	2.591

8.0 Conclusion

From the analysis conducted above on the pipe rack, following general conclusions were drawn:

- Utilization ratio of members the pipe rack has been calculated from Staad pro and all the structure members are not over designed. Further the stresses of each members are below the allowable stress value.
- The deflection has been calculated from Staad Pro on the nodes where maximum displacement will be occur during analysis and all the displacements are in allowable limits and if any accident occur due to hydrocarbon pipe leakage in pipe rack the structure will sustain the loads.
- A dynamic analysis has been performed by varying blast load (50ms to 200ms) on the Pipe rack to check the material properties particularly stresses. From the analysis we conclude that the stresses of all the beams and columns of pipe rack are in the allowable limits.
- A study has been performed to determine the Dynamic Amplification Factor (DAF) and DAF has been calculated from displacements on random nodes of the structure and reaction forces of the end supports of the structure. It will serve as a tool for quickly estimate the deflection, stresses and reaction forces for the dynamic blast by simply calculated the static analysis of any structure.

8.1 Future Work

In the above study, analysis of pipe rack has been performed by modelling H and I Steel sections. Same study has to be performed on the rectangular sections to check the variation in the behavior of the structure if explosion occur due to hydrocarbon pipe leakage and also calculate the dynamic amplification factor.

Further higher density value gaseous pipes will also be considered for explosion accident to investigate that how strong structure will be designed to sustain higher pressure loads and also study the change in dynamic amplification factor.

9.0 References

1. WALTER, R.M.D.a.R.J., Design of Structural Steel Pipe Racks. ENGINEERING JOURNAL / FOURTH QUARTER / 2010 / 241, 2010: p. 12.
2. Bausbacher, E., Process Plant Layout and Piping Design, 1993, PTR Prentice-Hall. p. 93.
3. Roy, S. Pipe rack Design Philosophy. 2009; Available from: http://www.civildesignhelp.info/pr.html.
4. (ASCE), A.S.O.C.E., Minimum DesignLoads for Buildings and Other Structures, in SEISMIC DESIGN REQUIREMENTS FOR NONBUILDING STRUCTURES2010. p. 184.
5. (AISC), A.I.o.C.C., Specification for Structure Steel Buildings: Allowable Stress Design Manual (ASD), in Frames and Other Structures1989 9th Edition. p. 799.
6. Aramco, S., Steel Piperack Design (SABP-007), 2002.
7. Forces, T.A.T.C.o.W.-I., Wind Loads Petrochemical Other Industrial Facilities, 2010.
8. Officials, I.C.o.B., Uniform Building Code-(UBC-1997), 1997.
9. Austin, Over-Design: Fact or Fiction? 1998. Volume 76.
10. Allwood, M.C.M.a.J.M. Utilization of structural steel in buildings. 2014; Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4075790/.
11. O'Rourke, L., The Mathematics of Simple Beam Deflection The Royal Academy of Engineering.

12. Design, T.C.o.B.R., Design of Blast Resistant Buildings in Petrochemical Facilities. 2010.
13. A. Khadid et al., " Blast loaded stiffened plates" Journal of Engineering and Applied Sciences,Vol. 2(2) pp. 456-461.2007
14. Kirk A. Marchand, Farid Alfawakhiri, "Blast and Progressive Collapse" fact for Steel Buildings, USA. 2005
15. M. V. Dharaneepathy et al.,"Critical distance for blast resistance design", computerand structure Vol. 54, No.4.pp.587-595. 1995.
16. P. Desayi and S. Krishnan, " Equation for the stress-strain curve of concrete". Journal of the American Concrete Institute, 61, pp 345-350. 1964.
17. T. A. Rose et al. "The interaction of oblique blast waves with buildings", Publishedonline: 23 August 06 © Springer-Verlag, pp 35-44, 2006.
18. T. Borvik et al."Response of structures to planar blast loads – A finite elementengineering approach" Computers and Structures 87, pp 507–520, 2009.
19. TM 5-1300(UFC 3-340-02) U.S. Army Corps of Engineers (1990), "Structures to Resist theEffects of Accidental Explosions", U.S. Army Corps of Engineers, Washington, D.C., (also Navy NAVFAC P200-397 or Air Force AFR 88-22).
20. Design against accidental loads recommended practice (DNV-RP-C204) by Det Norske Veritas 2008.
21. Bjerketvedt, D., Bakke, J. R. & van Wingerden, K. Gas Explosion Handbook. Gas Safety Programme 1990.

22. Mannan, S. Lees' Process Safety Essentials. 1st red. Waltham: Elsevier Inc.. 2014
23. Ir. W.P.M Merx. Methods for the determination of possible damage to people and objects resulting from releases of hazardous materials. CPR 16E, TNO, _rst edition, 1992.
24. Baker, W. o.a. Explosion Hazards and Evaluation. New York: Elsevier Scientific Publishing Company, 1983.
25. Merx, I. W. Methods for the determination of possible damage to people and objects resulting from release of hazardous materials - Chapter 2 The consequences of explosion effects on structures, Voorburg: The Hague: Directorate-General of Labour of the Ministry of Social Affairs and Employment. III, 1992.
26. Technical Sta_ of General Monitors. A Guide to the Characteristics of Combustible Gases and Applicable Detection Technologies. General Monitors.
27. Demeter G.Fertis. Dynamics and Vibration of Structures. John Wiley & Sons Inc,1973.
28. Abaqus/CAE 6.10-2 Documentation. Section 12, The Property Module. Dassault Systemes Simulia Corp., 2010.
29. Abaqus/CAE 6.10-2 Documentation. Section 20.2.3, Rate-dependent yield. DassaultSystemes Simulia Corp., 2010.
30. Tam V. et. al Walker S., Corr B. New Guidance on Fire and Explosion Engineering. 21st International Conference on O_shore Mechanics and Artic Engineering (OMAE2002), 2002.
31. Yasseri S. Iso-damage diagrams for blast resistant design. FABIG Newsletter Issue-42, 2005.

32. H. Bachmann et al. Vibration Problems in Structures. Birkhauser Verlag, Berlin,1995.
33. Technical Sta_ of General Monitors. A Guide to the Characteristics of Combustible Gases and Applicable Detection Technologies. General Monitors.
34. Demeter G.Fertis. Dynamics and Vibration of Structures. John Wiley & Sons Inc,1973.
35. John M. Biggs for Introduction to Strctural Dynamics
36. Design against accidental loads recommended practice (DNV-OS-C201) Structural Design of Offshore Units by Det Norske Veritas
37. Richard M. Drake, P.E., S.E., SECB and Robert J. Walter, P.E., S.E, 'Seismic Design of Structural Steel Pipe Racks', Engineering Journal (AISC), 4th Quarter, 2011
38. Mohammad Karimi, Naghdali Hosseinzadeh, Farshid Hosseini, Navid Kazem, Hamid Kazem, 'Seismic Evaluation of Pipe Rack Supporting Structures in a Petrochemical Complex in Iran' International Journal of Advanced Structural Engineering, Vol. 3, No. 1, Pages 111-120, July 2011
39. Akbar Shahiditabar, 'Pipe and Pipe Rack Interaction' International Journal of Applied Science and Technology Vol. 3 No. 5; May 2013.
40. David A. Nelson, 'Stability Analysis of Pipe Racks for Industrial Facilities',2008.
41. http://digitool.library.colostate.edu///exlibris/dtl/d3_1/apache_media/L2V4bGlicmlzL2R0bC9kM18xL2FwYWNoZV9tZWRpYS8xNzUwMTY=.pdf
42. Fabrizio Paolacci, Md. Shahin Reza, Oreste S. Bursi, 'Seismic Analysis and Component Design of Refinerypiping Systems',2011.

43. http://www.academia.edu/1773430/Seismic_Analysis_and_Component_Design_of_Refinery_Piping_Systems

44. Richard M. Drake And Robert J. Walter 'Design of Structural Steel Pipe Racks', Engineering Journal / Fourth Quarter / 2010 / 241.

45. Kasi V. Bendapudi, P.E., "Structural design of steel pipe supports" structure magazinefebruary 2010