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Evaluation of the Progressive Collapse on the Offshore Fixed Metal Platforms Strengthened by Circular Slit Dampers

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ABSTRACT

Slit dampers are one of the best solutions in order to improve seismic properties of offshore fixed platforms which are the economic arteries in countries with offshore oil fields. These types of dampers can be categorized as passive and yielding dampers. Because of their simple mechanism and also no need for special technology and material, they has been widely used in different applications. The progressive collapses in structures is so important. Because of that, in the recent years, many creditable international regulations have emphasized on the consideration of this type of failure (collapse) in the analysis and design of structures. At the end of this paper, it has shown that this type of damper could be very effective on the offshore fixed metal platforms behavior against earthquakes and progressive collapse.

KEYWORDS: offshore fixed metal platforms, circular slit dampers, progressive collapse, dynamic analysis

1- INTRODUCTION

The desire to achieve more energy resources leads to special focus to the offshore oil and gas resources and trying to extract them and so expansion in the construction of offshore platforms. These platforms are under severe dynamic loads such as earthquake in their service life. Nowadays, it is possible to control and analyze the structure function by using structure behavior control methods. This could be helpful in order to resist against environmental forces such as winds, waves and earthquakes which are neither static nor single component forces. For these types of forces the inertia effects are important and lead to dynamic magnification and cyclic response. Predicting the magnitudes of these loads are so difficult in comparison with gravity loads, because the temporal and spatial scale of these phenomena are small. As a result, by the dynamic point of view, new concepts have been developed in the field of preservation of structures and these concepts are in the different stages of development. If all safety factors are considered, reconstruction and repairing of a mounted platform is more cost effective in comparison with mounting and installation of a new platform. If we need to use a platform over its design life, it is essential to evaluate safety of structures by the appropriate methods. Nowadays, the use of passive control systems is one of the most widely used energy dissipation systems on offshore platforms. According to the numerous analytical and experimental studies, these types of dampers have the high energy absorption capacity under a stable hysteresis behavior. The noticeable advantages of these type of energy dampers are ease of construction, cost effectiveness and their application in the seismic rehabilitation of existing buildings and new structures. Many researchers use these types of systems in their offshore platforms: Vandiver and Mitome [1] used storage reservoirs as the tuned liquid damper (TLD) for the vibrational control of waves in fixed platforms. Lee [2] added viscoelastic materials on the jacket foundations in order to control offshore structures vibrations subjected to wave random loads. Ou et.al [3] investigated a numerical method for jacket platforms responses under ice loads using the viscoelastic damper. Jangid and Patil [4] evaluated the viscous, viscoelastic and friction passive control systems in jacket offshore platforms. Ou et.al [5] analyzed seismic vibrations in the steel jacket platforms by using the damping isolation system. Komanchi et.al [6] used friction dampers to strengthen Resalat (Persian Gulf) jacke platform. In this research, a type of jacket platform has been studied and analyzed for the process of strengthening and investigation of the nonlinear dynamic behavior of structures under seismic loading. This method has many advantages:

1- Non-elastic deformations are mainly focused on the seismic dampers and failure of the main structure are greatly reduced or completely eliminated.

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2- Adding the damper leads to reduce the lateral displacements which would also reduce to non-structural members damages.
3- Inspection, repair and replacement of seismic dampers could be done with the minimal cost and without evacuating residents after an earthquake by the strategic placement of seismic dampers.

Today, passive damping energy systems are an effective and inexpensive method for reducing the seismic risk in the structures [13].A number of mechanisms that can be used for passive damping are: the metal flow, metals phase transitions (Transformation of metals), sliding friction, Fluid orificing and deformation of solids and viscoelastic liquids. Among these methods, one of the most popular mechanisms is the metal flow. Many types of metal dampers with different flow forms have been proposed and used. De la Liera described two important features for these devices that help them to be efficient in engineering applications as follows:

1- These devices should have large energy dissipation (damping) capacity and stability (stable hysteresis cycle called sometimes fat)
2- They should have the appropriate model for the cyclical behavior (in fact, they should have a suitable mathematical model to predict the behavior). Nakashima point out to this view that in order to launch the power loss system faster, the flow of damper mechanism should be set at a lower level and on the contrary, in order to postpone the serious damage to the structures, the flow rate of main structures should be set at a higher level [10].

Progressive collapse [7] is the development of local failure (collapse) from one member to another member that ultimately lead to the failure of the whole structure or the disproportionate large part of it. Figure 1 fixed shows the number of incidents happened at the fixed and mobile offshore platforms that are based on the initiating event of the incident [8]. As it can be seen, more events are related to the structural failures. The importance of this type of failure has caused the many creditable international regulations discuss about this type of failure in the recent years [9].

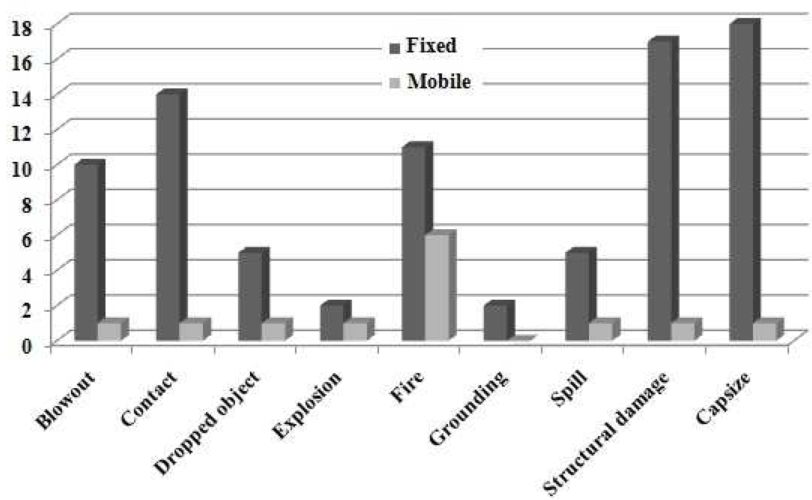


Figure1- the number of accidents happened in the mobile and fixed offshore platforms

In this paper, in addition to the investigation of the effects of this type of damper on the seismic behavior of the structure, by the elimination of some main parts that may damage, the offshore fixed metal platforms behavior against progressive collapse has been investigated. Finally, by analyzing results of structures dynamic analyses, some requirements is mentioned for the design of the platform and use of this type of damper in order to reduce offshore risks.

2- Properties of the studied jacket platform

The platform has been studied in this research is a jacket type fixed metal platform (figure 2 and figure 3). The platform has four main bases with of 29.7 meters heights. The platform bases slope varies a 1:10 ratio to a height of 24 m. The depth of sea water at the platform building site is 18.2 meters. Due to the presence of the cylindrical oil tank with the 2000 m^3 volume and other equipments on the deck, the total mass of the deck are considered 2000 tons and the jacket mass regarding t to the circular members used in it are considered 350 tons. Modeling the behavior of jacket platforms is much more complicated than other structures. ABAQUS finite element software is used in order to modelling the process. Steel materials are modelled using two linear stress-strain curves with the after yielding slope equals to %3 E. The elastic modulus, Poisson's ratio and density of steel are considered 2.05×1011 N / m^2, 0.3 and 7850 Kg /m^3 respectively. In order to the calculation of the effects of the upper deck on the jacket structure, a rigid plate is used that the deck mass is focused in the form of 8 concentrated points. The jacket members are modelled using beam elements in ABAQUS software. The structure have been affected by two accelerograms, Tabas and Northridge that are scale to 0.35g.

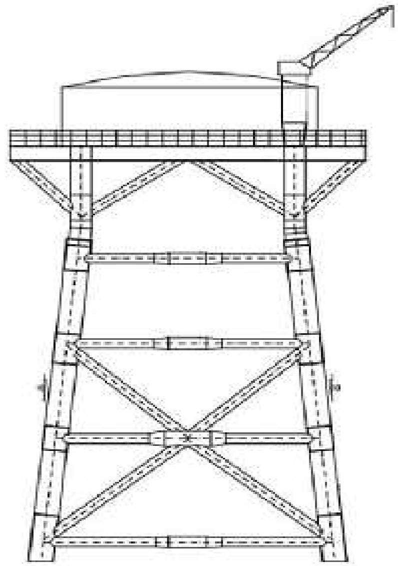


Figure 2- The offshore fixed metal platform

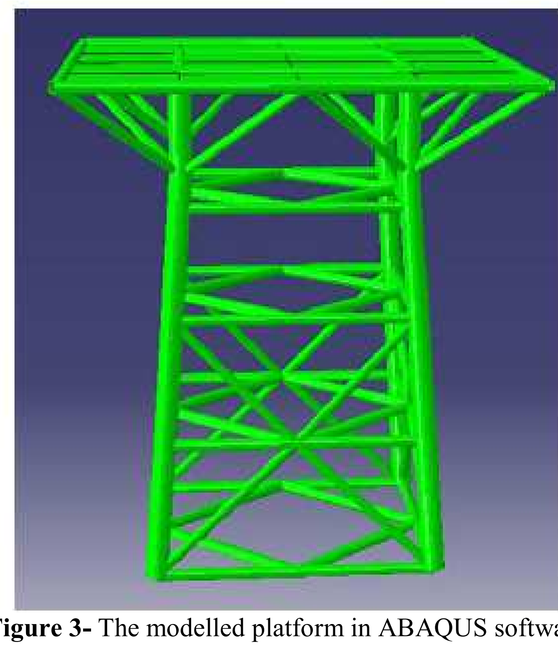


Figure 3- The modelled platform in ABAQUS software

Because the inspection and changeability of the circular slit dampers and the diving problems in the lower depth of the sea tried in this investigation it is tried to locate the dampers in areas close to the sea level, so four dampers has been used in the level of 22 meters of the sea level and 1.8 meters above the water level, near the join places of jacket main beams to thebase. Figure 4 shows the schematics of damper connection to the platform.

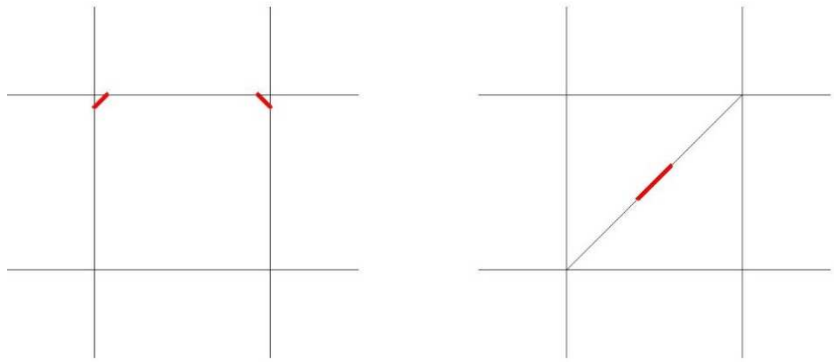
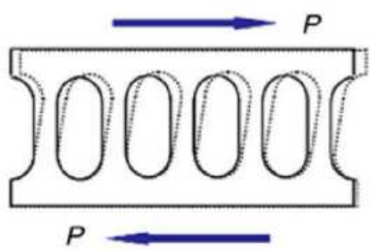


Figure 4- The damper connection to the platform place in offshore platforms

3- Introduction of Circular Steel Slit Dampers (CSSD)

These dampers are similar to the SSD dampers of the SSD with the difference that instead of creating slots in the webs of the I-shaped profiles, slots are created in the wall of the pipe. These types of dampers are so cost effective, because they can be produced easily even by the tubes in the market. SSD dampers have been investigated and analyzed in different forms, experimentally and numerically, but because of their high production cost and also difficulty in their production (due to their shape) they have been rarely used. By using a circular area in dampers the piece will be more cost effective, easily produced and also this form increases its efficiency. This type of damper can be used for improvement of the seismic behavior of the present and also new structures. Figure 5 shows a schematic of the used CSSD damper and also SSD damper.



(b)

(a)

Figure 5-Schematics of (a) a CSSD damper (b) a SSD damper

According to the Figure 6, the metal cylinder shown in Figure 5 are surrounded by two internal and external cylinders in order to show a higher capacity and also prevent leaving the steel strip dampers from the loading screen.

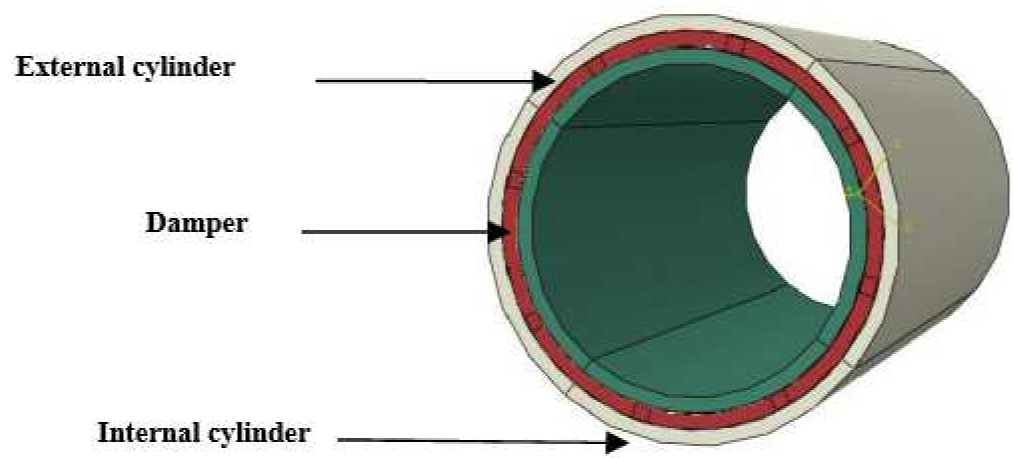


Figure 6- the CSSD damper components

4- The strengthened structure performance against the progressive collapse

As well as other structures, in these systems, the regulations about the stability of the entire structure and its component should be examined and analyzed properly. If the structural design criteria are in such a way that the structure enable to absorb a local failure, the damage will be remained in the structure will not spread to the other parts. Otherwise, the damage will not remain locally and spread to the other parts of the structure and so will ultimately lead to failure and collapse of the entire structure. In fact, in this case, a failure chain mechanism can occur which is known as the progressive collapse phenomenon or the domino effect.

If due to the local damage in the structure, suddenly the bearing capacity of a member or a set of structural components loss severely, the load flow resulting from the local collapse (failure) may be so rapid that other structure members cannot absorb the redistributed load quickly enough during the load distribution process. Therefore, immediately after creating a local collapse in the structure, a temporary instability occurs in the structural balance. The structure suddenly transform to a new balanced condition in the same load level in order to find a new stable balance condition. Transforming to this new condition needs sudden and large deformation in the structure and leads to severe dynamic effects. This phenomenon is called the "dynamic snap through phenomenon". The dynamic effects resulting from this phenomenon lead to apply extra forces to the structure and enhance the redistribution of forces resulting from the local failure and so increase the risk of failure in the structure. In this case, the static analysis is not enough to properly evaluate the collapse behavior of structures. So, a good dynamic analysis should be done in order to consider and evaluate dynamic effects resulting from the dynamic snap through correctly in the analysis. Figure 7 and 8 shows the structure collapse behavior without and with the dynamic snap through.

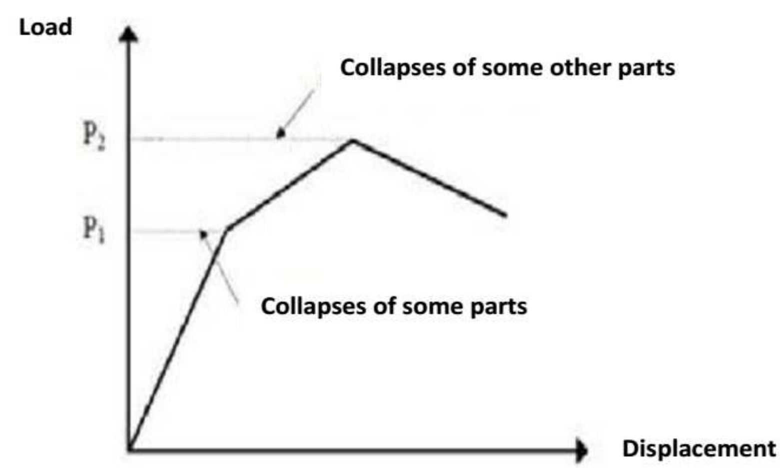


Figure 7- the structure collapse behavior without the dynamic snap through

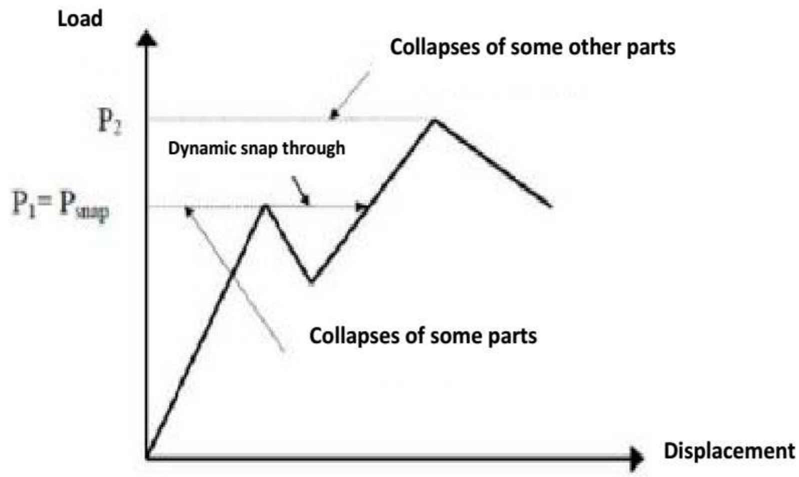


Figure 7- the structure collapse behavior with the dynamic snap through

5- Design of a CSSD damper on a jacket platform

In order to analyze the effect of the CSSD damper on the structure response, it is essential to determine the pattern for the damper behavior. This pattern can be obtained using force-displacement response of the analysis done by the ABAQUS software. In order to shorten the analysis time in this investigation, only damper was modelled and modelling of internal and external walls has been ignored. Instead of that, the damper radial wall motion was prevented by defining boundary conditions in the model. It should be noted that in order to verify the authenticity and accuracy of this act, the load-displacement curves of two models, with and without the support walls has been compared together (see Figure 9). Results show that these models match together very well.

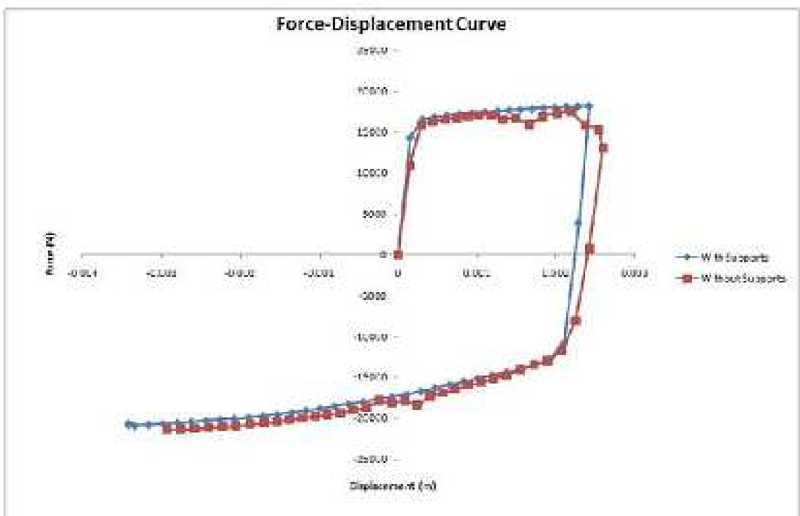


Figure 9- The load- displacement curves for two models: with and without supports

According to the previous researches [14], Characteristics of the best example of this type of damper that its behavior is better than the other samples are shown in Table 1. Some of the main noticeable properties of this sample are: the higher hardness, bigger yielding force and so higher damping (energy dissipation) rate (the load- fat displacement curve). Figure 10 depicts the load-displacement curve of this sample.

Table 1- properties of the damper used in the structure

Model Name	The Slot Width (Cm)	The Slot Length (Cm)	The Primary Hardness (N/m)	Yield Force (N)	Final Force (N)	The Dissipated Plastic Energy(J)
B1,30	1	1.81	163657419.4	25366.9	28181.6	**164.086**

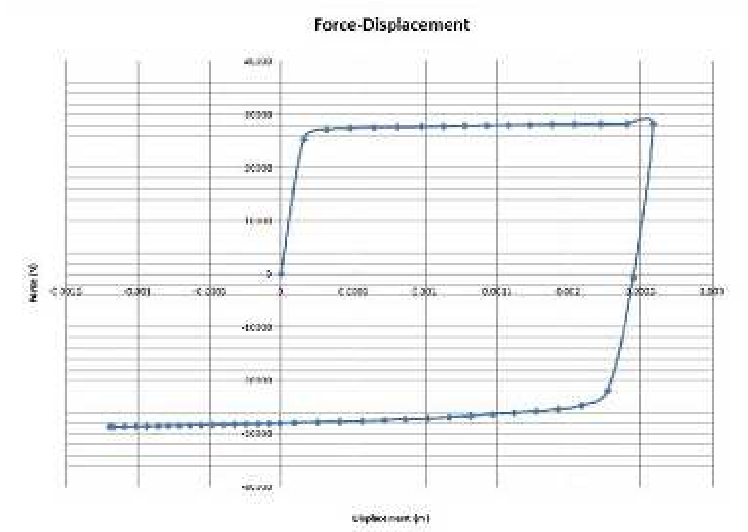


Figure 10- the load displacement curve of the model used in the structure

The Damper must be placed in the structure in such a way that there should be deformed in the presence of relative displacement of levels due to lateral loads. The design should be such that the damper goes to the plastic form before the structural members. If there is lack of accuracy in placing and design of this type of damper, the damper may absorb the force like a structural element and will not show a plastic behavior for energy dissipation (damping) [15]. The most important note should be considered in the use of these dampers is determining the optimum slope load. For this investigation, if the combination of relative displacement of the deck and shear of the platform base are two main factors show the damper performance and it is defined with SPI (equation 1), the optimum performance of the damper will be obtained when the SPI is at the minimum level.

$$SPI = \sqrt{R_D{}^2 + R_F{}^2} \qquad (1)$$

$$R_D = \frac{D_F}{D_P} \qquad R_F = \frac{V_F}{V_P} \qquad (3)\ ,\ (2)$$

Where:
D_f: is the maximum displacement of the structure in the presence of the damper
D_p: is the maximum displacement of the structure in the absence of the damper
V_f: is the maximum base shear of the structure in the presence of the damper
V_p: is the maximum base shear of the structure in the absence of the damper

R_D and R_F are the response decrease factor and base shear respectively and could be calculated According to equations 2 and 3. Figure 11 and 12 shows the SPI under two earthquakes: Northridge and Tabas respectively. The place which has the minimum SPI value is related to the best performance of the damper in the structure.

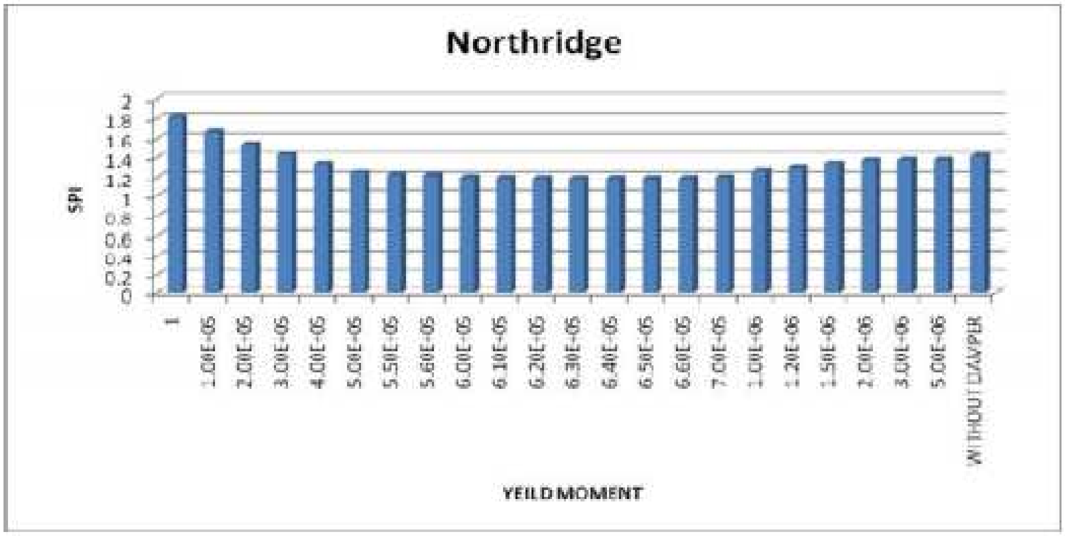


Figure 11- the analyzed damper in the Northridge earthquake

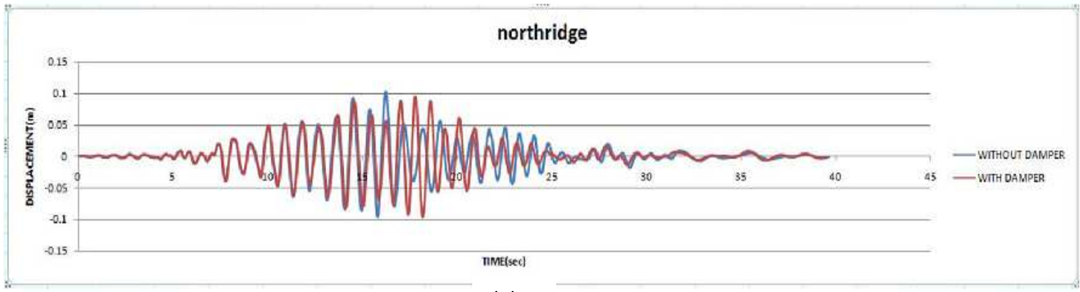
Figure 11- the analyzed damper in the Tabas earthquake

6- Analysis results of the jacket platform

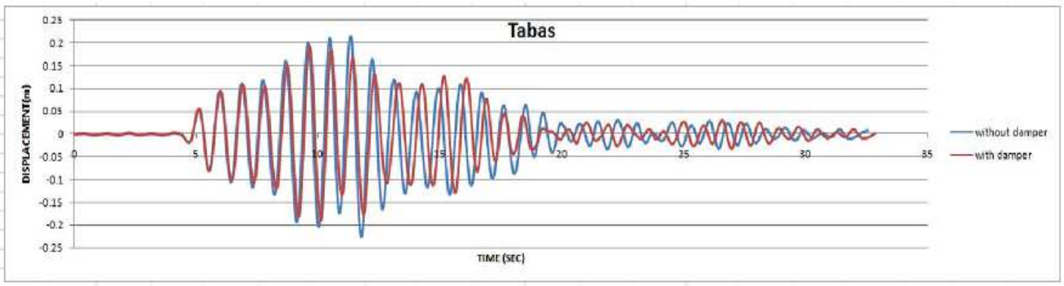
Table 2 shows the maximum relative displacements of the deck and the bases shear for the Northridge and Tabas earthquake records. The relative displacement time history in the deck and the base shear time history are shown in Table 13 and 14 respectively. It can be seen that by using this damper near the junction of the column to the jacket base, the maximum displacement in the deck and the base shear are reduced [11].

Table 2- summary of the non-linear dynamic analysis results with CSSD dampers

Earthquake	Maximum acceleration (g)	System type	The relative displacement maximum value (cm)	The base shear maximum value (MN)	The relative displacement reduction(%)	The base shear reduction (%)
NORTHDRIGE	0/35	Without damper	10/02	11/4	13/02	**18/33**
		With damper	8/71	9/31		
TABAS	0/35	Without damper	22/46	22/5	14/97	**18/67**
		With damper	19/1	18/3		

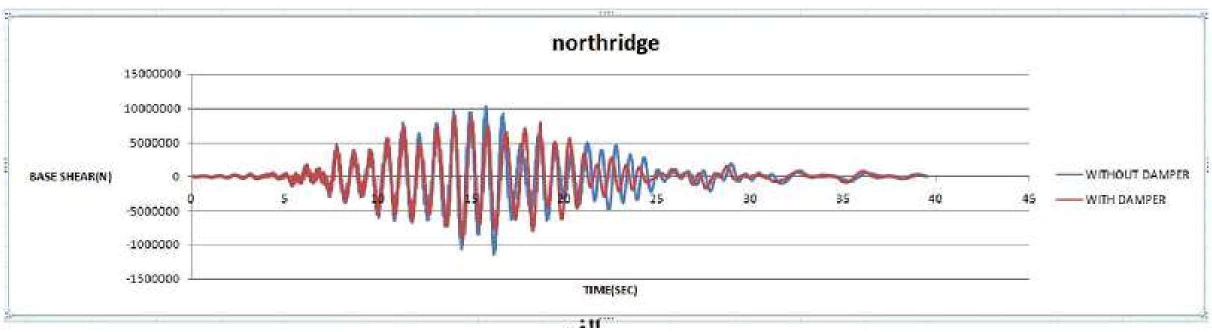


(a)



(b)

Figure 13- a and b) time history diagrams for the relative displacement of the platform in Northridge and Tabas earthquake respectively



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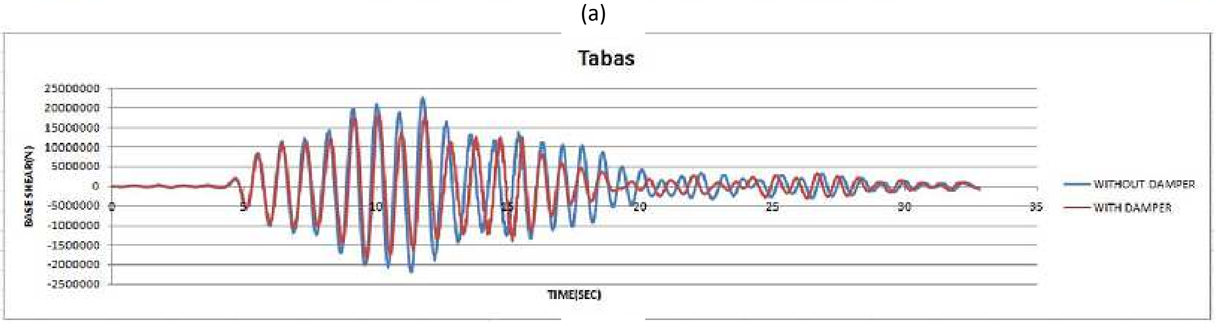

(b)

Figure 14- a and b) time history diagrams for shear base of the platform in Northridge and Tabas earthquake respectively

During the analysis, 2 columns of the offshore platform due to have the maximum axial force besides other columns were eliminated and then the special loading was introduced. In accordance with the recommendations of the GSA regulation [12], during the progressive collapse analysis, the defined load on the structure can be defined as follows:

$$U = \alpha(DL + 0.25LL) \tag{4}$$

In this equation, DL states for the Dead Load and LL is related to the Live Load. According to the point that the probability of the absence of whole live load during occurring a phenomenon is very low, the 0.25 coefficient is used for that in the equation. The magnification coefficient, α is used in order to take in to account the dynamic effects (only in static analysis) to the load feature and the value for α is considered 2. Figure 15 shows the loading method during a non-linear static and non-linear dynamic analysis.

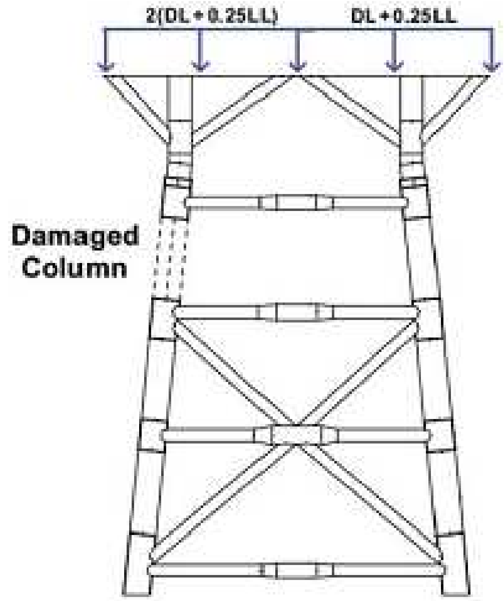

Figure 15-the loading method for the progressive collapse analysis

In the progressive failure analysis, according to the regulations recommendations, as shown in Figure (16), the gravity loads linearly increase up to 14 seconds (for 10 times or more of the structure original period) increases and at this time, it reaches to its maximum value. After that, for 2 seconds it is remained constant in order to avoid any types of dynamic excitation. When the gravity loads are fully applied during the 16 seconds, the load of each column are eliminated during 0.1 time of the structure original period (0.14 s) and then the structure behavior will be analyzed with and without the damper.

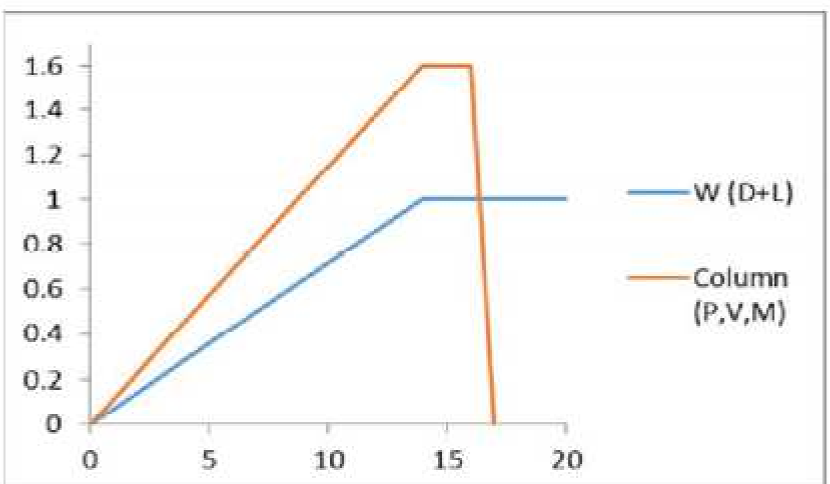

Figure 16- the loading method in the progressive collapse analysis

With performing a non-linear dynamic analysis in every condition, the Demand Capacity Ratio (DCR) for every parts of the jacket can be calculated as:

$$DCR = \frac{Q_{UD}}{Q_{CE}} \quad (5)$$

Where:

Q_{UD} is the force resulted from the analysis in the member or connection

Q_{CE} is the estimated capacity in the member or connection

When the DCR value of every part exceed the maximum allowed value, the member is considered disruptive. Calculation of the axial, shearing and bending capacity of the members usually perform without the consideration of the safety factors that are mainly in the regulations. Table 3 shows DCR values for the members in two different conditions, with and without a damper.

Table 3-Maximum DCR values in the progressive collapse analysis with and without a damper

Member	Psition in the structure	Total number	Number of members with maximumDCR	Max DCR with Damper	Max DCR without Damper
Column	At the lowest level	20	2	1/12	2/7
Beam	At the front side (diagonal) the removed column	32	9	0/93	0/75
Bracing	Near the removed member	16	7	0/78	1/38
The pressure members holding the deck	At the front side (diagonal) the removed column	12	3	1/06	1/18

According to the table, it can be seen that the DCR value decrease severely for different parts of the structure in the presence of the damper. Although the amount of decrease in the pressure members holding the deck is very low and also the increase can be seen for the beams, the most important thing about the jacket platform is the effect of the damper on the column and bracing members of the structure. After performing a non-linear static analysis, the structure behavior can be analyzed and with the aim of information obtained from the non-linear dynamic analysis, the effect of a damper in a structure during a progressive collapse could be observed. For this purpose, according to Figure 17 and 18, the time history response for the axial forces of other columns could be shown during removing the considered column for the offshore fixed metal platforms.

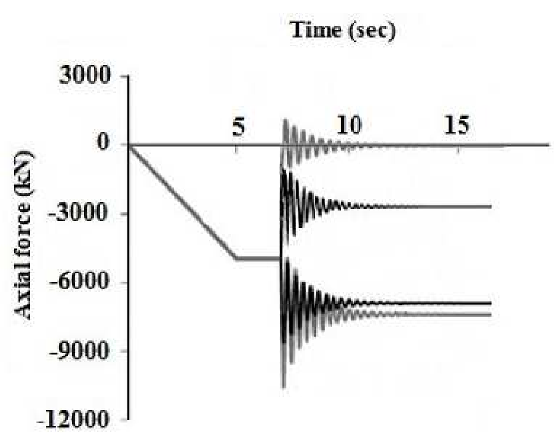

Figure 17- The offshore platform without a damper

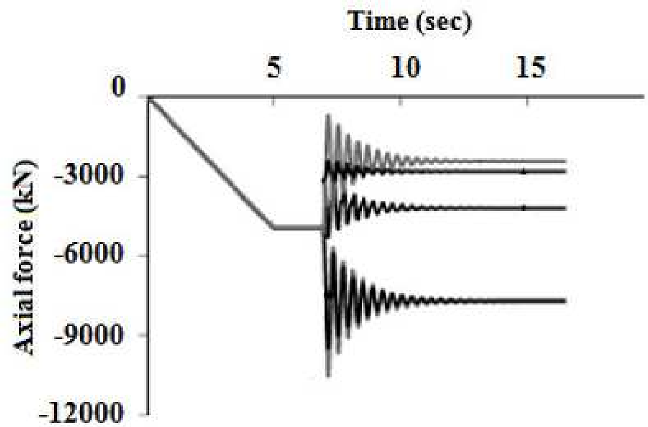

Figure 17- The offshore platform with a damper

The axial force created in the columns show that their axial forces change less in the design with damper in comparison with the design without the damper. This fact prove the efficiency and benefit of the presence of a damper in the structure. So, the structural system with a damper can resist against removing the members very well and also the offshore fixed metal platform strengthened by the damper have a good function and efficiency against the progressive collapse in such a way that the damper could even prevent failure and remove of the other column.

7- Conclusion

In this method, instead of occurring the energy dissipation (damping) in the in the main parts of the structure and so lead to their failure or damage, damping is took place at the CSSD dampers that are designed for this purpose and installed in the platform. As a result, the main parts of the platform such as columns and beams are kept away severe damages. In this paper, the positive and efficient effect of a damper in the structure has been mentioned such as: the good behavior of this damper for the energy damping in the structure, Reduction in the base shear and reduction in the maximum displacement of the deck. Also, the good results obtaining from the use of this damper during a progressive collapse has been mentioned.

From the presented figures, it can be anticipated that the damper can show a good performance during a progressive collapse in addition to reduction the displacement and base shear during an earthquake. These figures also show the reduction of axial forces changes in the columns and bracing members. In addition, presence of a damper in the structure during a progressive collapse leads to reduce the DCR value for the structural parts of the jacket platform.

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