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APPLICATION OF HYDE SEISMIC PROTECTION SYSTEM IN MEDIUM RISE RC BUILDINGS WITH SOFT STOREY IN BANGLADESH

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Abstract

Bangladesh has a long history of earthquakes and the largest one that occurred here is of 8.7 magnitudes Great Indian Earthquake. Several international researchers showed the possibility of large earthquake to occur in this area in near future, which will cause damages of infrastructures resulting in loss of human lives. It has been observed that most of the existing medium rise reinforced concrete (RC) buildings in the urban areas of Bangladesh have soft ground floor which have been designed without following proper seismic design code, hence do not full fill the demand strength required against an earthquake. These existing medium rise RC buildings with soft ground floor need to be retrofitted with a suitable technique. In this study the performance of Hysteretic Device (HYDE) system in a medium rise RC building selected from an urban area of Bangladesh is checked by SAP 2000v15 software. HYDE is a passive control system especially developed for soft storey seismic control of medium rise building structure. A nonlinear time history analysis is performed using three earthquake data developed from normalized acceleration response spectra to check the performance of HYDE. From the analysis, design HYDE force is achieved as 6300 kN. It has been observed from the generated HYDE curve that, the overall horizontal displacement against the seismic force is reduced from 0.176 m. to 0.035 m. Which means, by the application of HYDE system, 80% of displacement can be reduced.

Keywords: Seismic protection, passive control, Hysteretic Device, structural control, soft storey seismic control.

1.0 INTRODUCTION

The growth rate of medium rise reinforced concrete (RC) structures is very high in the urban cities of Bangladesh and very few of those structures have got seismic resistivity of its own (Potty and Sirajuddin 2011). The country is one of the most earthquake prone countries in the southern part of Asia (Ahmed et al., 2005). The location of the country is near the junction of the Indo-Australian plate and Eurasian plate. Four major sources of seismic activity were defined by Bolt (1987) with probable magnitude for each source; these are the Assam and the Tripura fault zones containing significant faults capable of producing magnitude 8.0 and 7.0 in Richter scale respectively. And earthquake with maximum magnitude 7.3 in Sub Dauki fault zone and 7.0 in Bogra fault zone. That is why the existing medium rise buildings of the urban areas in Bangladesh which were built without following proper seismic design code now urgently need to be retrofitted with reliable seismic protection system.

Providing the structural safety and comfort by controlling the internal forces and displacement within the particular limits is the purpose of seismic protection system of building (Torunbalci 2004), which is also called as seismic retrofitting. The primary goal of seismic retrofitting of a building's superstructure should be the correction of the main weaknesses relating to seismic performance. Besides the connection between all the existing structural members, the important aspects are the transfer of the effects of the seismic action from the ground through the foundation. In addition, the retrofitting strategy must take into consideration the future use of the building (Wenk 2008).

The HYsteretic DEvice or HYDE system is a passive superstructure control system. The system is designed such that it physically limits the seismic forces in the system and concentrates deformations in dissipative device (Dorka 1994). HYDE system can be applied to new structures but it is most suitable for retrofitting, especially when it comes to the so-called soft storey structure. A well-designed HYDE system can dissipate around 85% of seismic input energy (Schmidt and Dorka 2004). The system has been validated by large scale experiments at the ELSA Laboratory of the European Union in Ispra, Italy.

Soft storey structures are available in many of the medium rise RC buildings in the urban areas of Bangladesh which most of the cases have not been designed following proper seismic design code. According to a study by Comprehensive Disaster Management Program (CDMP 2009), around 25% of the building stock in urban areas of Bangladesh have soft ground floor and most of which are the residential buildings with open parking area. In such building structure the device can be attached in the soft storey to concentrate the motion in it, while the other storeys above react as rigid body. To choose the necessary yielding force of HYDE with respect to the allowed storey drift in the soft storey, a design curve is determined. This design curve shows the relationship between the storey displacement and the yield force of the device (Gleim and Dorka 2008). In this study HYDE system performance is evaluated against the seismic condition of Sylhet city in Bangladesh which is in the high-risk zone according to seismic map of Bangladesh National Building Code (BNBC 2020).

2.0 METHODOLOGY

2.1 Structural Principal of HYDE System

The seismic drift control mechanism in HYDE system is an arrangement of rigid block coupled by elastic plastic steel or friction devices aiming to dissipate the largest part of the input energy in this device. It is the force limiting characteristics of the seismic link (Figure 1) through the Hyde force that gives the designer complete control over the forces in the remaining structure thus protecting the masonry walls that otherwise would perform poorly under earthquakes. To stabilize this mechanism during the nonlinear action of the devices, an elastic stiffening system in parallel to these devices is needed (Figure). But the stiffness may not be too high, since otherwise the energy dissipation in the devices is reduced (Gleim and Dorka 2008).

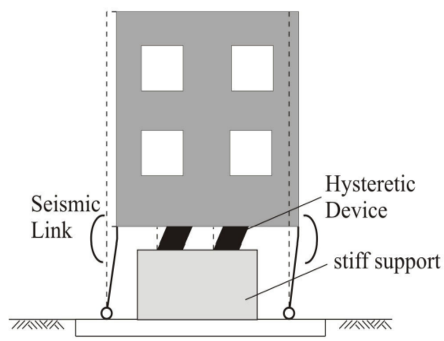


Figure 1 HYDE system mechanism

The system consists of a very stiff Primary Horizontal load bearing System (PHS) with Seismic Links (SL) where HYDE systems are placed and a conventional soft Secondary Horizontal load bearing System (SHS) shown in Figure 3. The PHS must be very stiff in order to concentrate horizontal displacements in the seismic links where the HYDE system dissipates most of the input energy. The HYDE system must show almost ideal stiff-elastic-plastic behavior to dissipate a large amount of input energy. The SLs can transmit only the maximum HYDE force as storey shear to the adjacent structural members. Therefore, the remaining elastic part of the structure is protected from overloading. This unique feature of the HYDE system concept allows the designer to choose a shear force envelope that is suitable for the structure and design its conventional members accordingly. The remaining task is to verify the displacement capabilities of the chosen mechanism, e.g. in the locations of the seismic links. The design limit of the HYDE System is defined by the elastic deformation limit of the SHS, usually columns in the storey where the SL is placed (Schmidt and Dorka, 2004). To describe the behavior of the seismic links with their HYDE system, a Bouc-Wen type hysteresis law is used to describe the shear force transmitted through each SL. This law is numerically quite stable, which is a necessity when analyzing stiff-ductile systems.

2.2 Design Curve of Hyde System

A HYDE force versus horizontal displacement design curve as shown in Figure 2 is developed to choose the necessary yielding force of the device. The relationship between the horizontal displacement of the structure and the yield force of the device is represented by this design curve. The value of horizontal displacement is limited by the building without HYDE system and by the devices being strong enough that the storey does not yield (Gleim and Dorka, 2008). The design curve can be calculated by nonlinear time history analysis using SAP 2000 software for different yield levels of the devices. Artificial accelerogram matching the elastic code design spectrum can be used (Idrizi et al., 2012). Many codes require at least 3 of them for design (Gleim and Dorka 2008).

2.3 Representation of HYDE in SAP 2000v15

SAP 2000v15 does not represent the HYDE system in a specific option called shear panel. But according to Dorka et al. (2004), it provides a law recommended simulating the behavior of the shear panel which is "Bouc-Wen hysteresis law" (Wen 1980). Therefore, the shear panel is defined as a link element (Figure 3) in the SAP 2000v15. The software permits the complete definition of Bouc-Wen properties through four parameters (*k, y, r* and *e*) and the link force deformation characteristics which is,

$$f = r \times k \times d + (1\text{-}r) \times y \times z \qquad (1)$$

Where, f = restoring force, r = post yield stiffness ratio, k = stiffness, d = link deformation, y = yield strength, z = hysteretic variable. The shear panel is inserted into the link between bracings in the soft storey floor beams (Figure 3) and is a very stiff element.

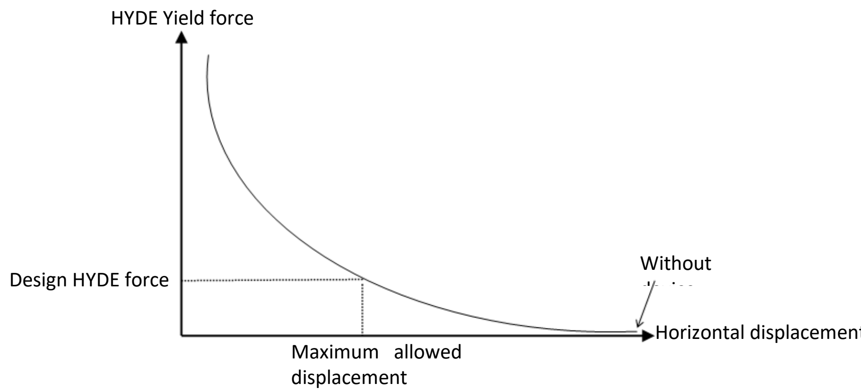


Figure 2 HYDE system design curve

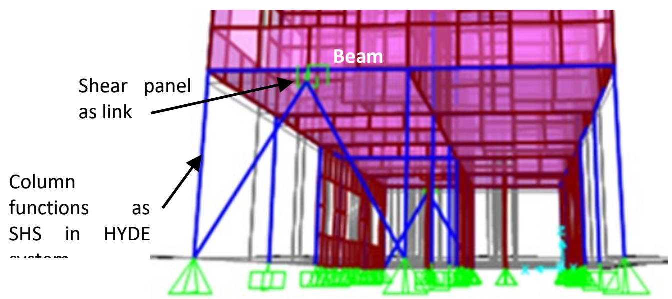


Figure 3 HYDE shear panel represented as link in SAP 2000v15

2.4 Time-history representation of earthquake

Record of the accelerations, also known as accelerogram is used and introduced as functions in SAP 2000v15 to simulate earthquake. According to Tahmmed et al. (2012), Bangladesh National Building Code provides normalize acceleration response spectrum. If the use of artificial accelerograms is needed they shall not be generated using the design spectra as said Mazzolani (2000). All the earthquakes used in this study are generated from the analyzed acceleration response spectrum. When HYDE system reaches the yielding force, they start behaving in non linier which is demanded to use non linier methods to simulate the behavior of the models during earthquake. To perform time history analysis, data for three artificial earthquakes based on earthquake response spectrum are used naming EQ-1, EQ-2 and EQ-3 (EQ= earthquake). Each earthquake data has 1500 steps with 0.01 increments. Newark parameter γ = 0.5 and β = 0.25 is taken. Mass and stiffness proportional parameter have been set to 0.01. Shear panel has been modeled as Bouc Wen type hysteresis law with stiffness k = F_y/0.005, post yield stiffness ratio *r* = 0 and yield exponent *e* = 2. As the study building is a medium rise residential building in Bangladesh, the load combination according to BNBC (2020) is used which is,

P = 1.4 (Dead Load + Live Load + Earthquake Load) (2).

2.5 Mathematical Model of the Case Study Building

For this study, a five-storey medium rise residential RC building (Figure 4 a) is selected from a residential area of Sylhet metropolitan city in Bangladesh. According to BNBC (2020) the city is in Zone-04 which is a high seismic risk zone with zone co-efficient 0.36. The case study building contains ground floor soft storey (storey of a building that is significantly more flexible or weak in lateral load resistance than the stories above it, generally happens because of large opening) which makes the structure ideal for the application of HYDE system. The building has three frames in longitudinal (east-west) direction and six frames in transverse (north-south) direction (Figure 5). Column center to center length at longitudinal direction is 21.5

m. and transverse direction is 6.4 m. (Figure 5) and the storey height is 3 m. Figure 4 b shows the three-dimensional (3d) simulation of the building. The structure is modeled in 3d finite element modeling with elastic beam, column, masonry wall and slab with the X axes representing longitudinal direction, Y axes transverse and Z axes for the vertical direction. The building was defined by means of different finite elements available in SAP 2000v15. Each structural component of the building is modeled with the elements which is capable to produce the most appropriate behavior. Type shell option is used to represent slab and wall and frame is used to represent column and beam. The model is constrained at X, Y and Z direction at supports. To model the brick masonry wall two dimensional finite elements namely shell with 4 nodes is used. The size of the shell unit is taken as one square foot to reduce the analysis time. To model the building, it was considered all the masonry walls deducting the opening for windows and doors. The opening for windows and doors is done following the real time location and tried to follow the real opening area. Brick wall is considered in the model because these significantly affect the stiffness and strength of the structure. The thickness of the wall panels has been adopted as 125 mm. with necessary strength compressive strength of brick. To simulate the reinforced slab of the building thick shell element option is chosen. It is considered that the floors do not have axial deformation. Frame element option is used to represent the columns and beams. The location of stair case is remained blank. And all the decorative modeling has been avoided.

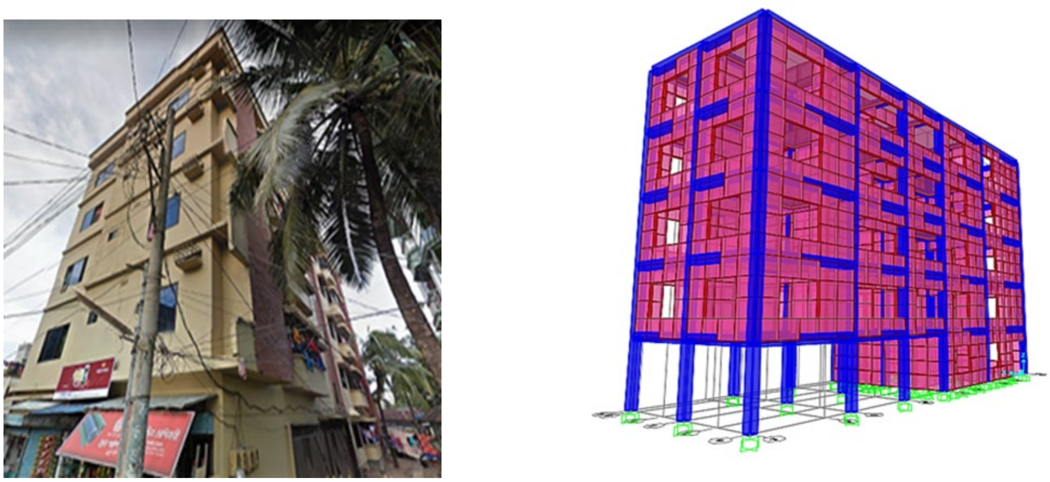


Figure 4 (a) Selected 05 storey residential building from Sylhet Metropolitan City; (b) 3D mathematical model of the selected 05 storey building (SAP 2000v15);

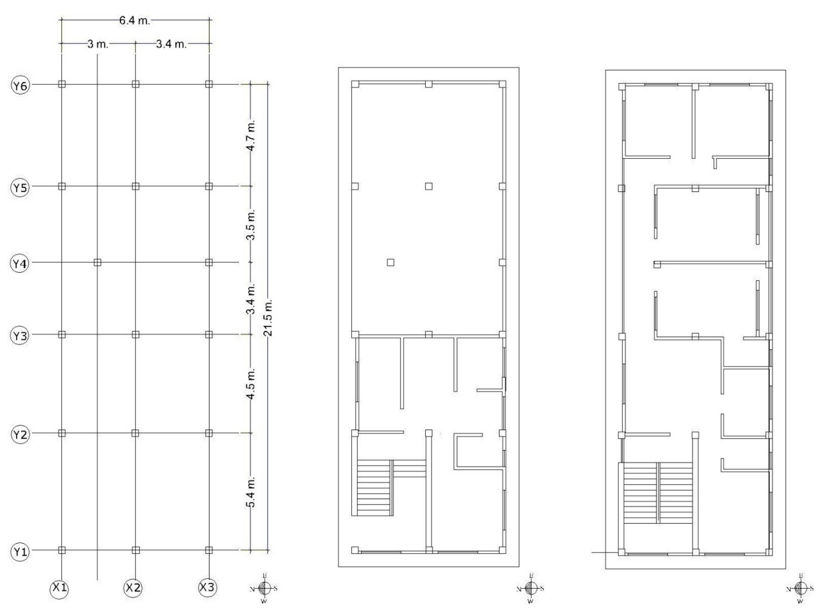


Figure 5 Column layout, GF and Typical floor plan

2.6 Construction design formula of low-cost shear panel device

Low-cost shear panel device (SPD) is used for HYDE system. These devices are made of mild steel to provide a large displacement capacity under extensive yielding. Once the design HYDE force (F_y) is determined from the HYDE force – Moment curve, the size of the SPD can be determined from the following equation (Schmidit and Dorka 2004).

$$F_y = f_y \cdot \left(\frac{t_{web} \cdot h}{\sqrt{3}} + \frac{t_{flange}^2 \cdot b}{h} \right) \quad (3)$$

Where, f_y = yield stress, h = height of the shear panel, b = width of the shear panel, t_{web} = web thickness, t_{flange} = flange thickness.

3.0 RESULTS AND DISCUSSION

3.1 HYDE curve and design HYDE force

For this study HYDE device represented as "link" in SAP2000v15 is used at one location of ground floor (Figure 9) and result for that one link is analyzed. However, it may not be limited to one link or one location practically. After the collection of data for three earthquake accelerogram, a fixed HYDE yield force (e.g. 1200 kN) is used to determine the strongest earthquake from the three against which maximum storey drift and moment is achieved. The result of three earthquake data against 1200 kN HYDE force is recorded in Table 1. It can be observed from the Table 1 that maximum storey drift and moment is achieved from EQ 02 data which is 0.1495 m. and 764.37 kN-m. respectively. Figure 6 shows the accelerogram of EQ 02 which will be used to determine the design HYDE force. Once the earthquake accelerogram is determined for the specific link, non linier time history analysis is run for different Hyde force to determine design Hyde force. Overall horizontal displacement and moment against different HYDE force (from 0 kN to 10000 kN) is recorded in Table 2. The design Hyde force is determined comparing the design moment of vertical load bearing member (here column). Two different graphs are plotted using the values of displacement and moment which is the HYDE curve. Figure 7 shows the normalize acceleration response spectra for the soil type SD which is the site soil class of the case study building. Figure 8 shows the shear force will be transmitted through seismic link due to hysteresis loop characteristics of an elastic-plastic device as per Bouch Wen type Hysteresis law.

Table 1 Selection of EQ accelerogram

EQ Accelerogram	Hyde force (F_y)	Overall horizontal displacement (m.)	Moment (kN-m.)	Axial force of bracing (kN)
EQ 1	1200	0.05528	294.96	1796.41
EQ 2	**1200**	**0.1495**	**764.37**	**1909.48**
EQ 3	1200	0.1318	682.78	1949.26

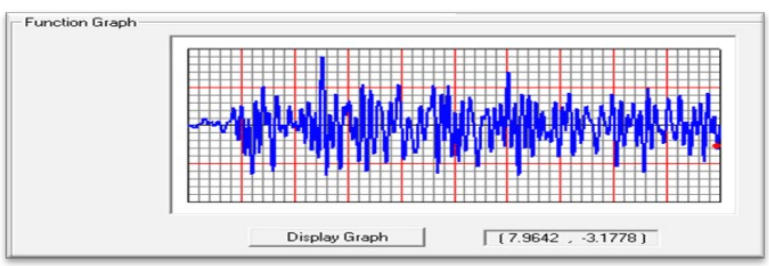


Figure 6 EQ 2 accelerograms used to perfom time history analysis

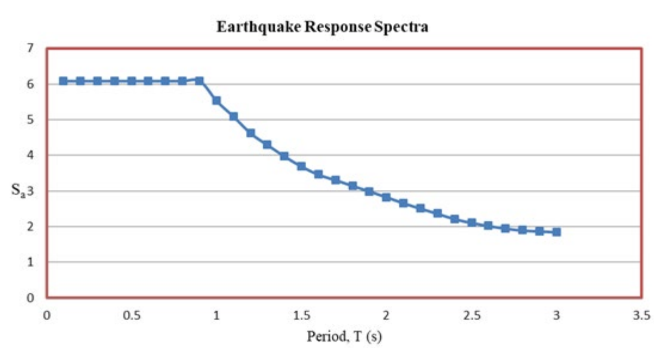


Figure 7 EQ 2 Normalized acceleration response spectra for soil type (SD) taken from BNBC (2020)

Once the earthquake accelerogram is determined for the specific link, non linier time history analysis is run for different Hyde force to determine design Hyde force. Overall horizontal displacement and moment against different HYDE force (from 0 kN to 10000 kN) is recorded in Table 2. The design Hyde force is determined comparing the design moment of vertical load bearing member (here column). Two different graphs are plotted using the values of displacement and moment which is the HYDE curve. Figure 8 shows the shear force will be transmitted through seismic link due to hysteresis loop characteristics of an elastic-plastic device as per Bouch Wen type Hysteresis law.

Table 2 Hyde force vs horizontal displacement and moment

EQ Accelerogram	Hyde Force F_y (kN)	Horizontal Displacement (m.)	Moment (kN – m.)
EQ 2	0	0.17578	
	1200	0.14699	764.37
	3000	0.08634	443.3
	4000	0.06218	316.18
	5000	0.04677	233.57
	6000	0.03643	177.74
	7000	0.02858	135.3
	8000	0.02188	99.12
	9000	0.01624	68.69
	10000		47.41

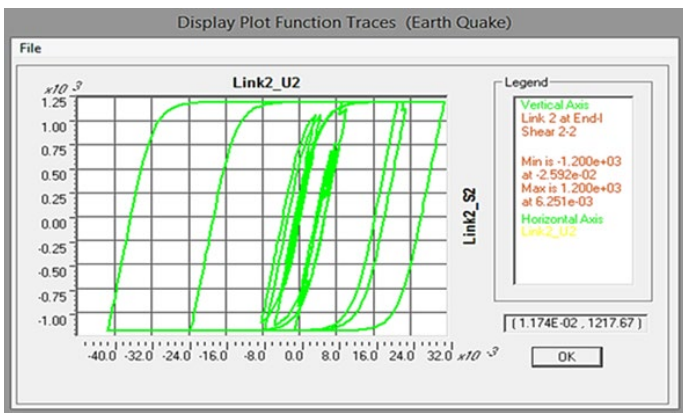
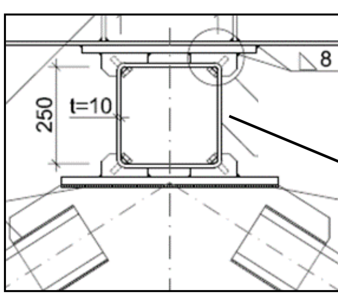


Figure 8 Hysteresis behavior of HYDE link under EQ 2



Typical 2D drawing of Shear Panel

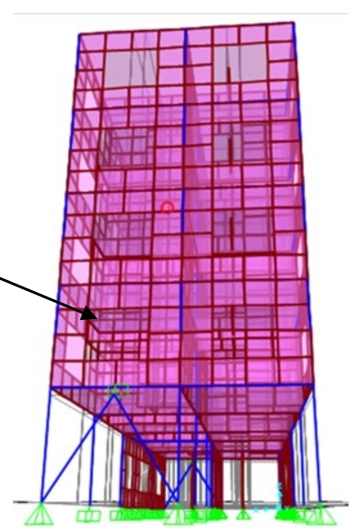


Figure 9 Application location of Hyde shear panel device as 'link" in ground floor (SAP 2000v 15)

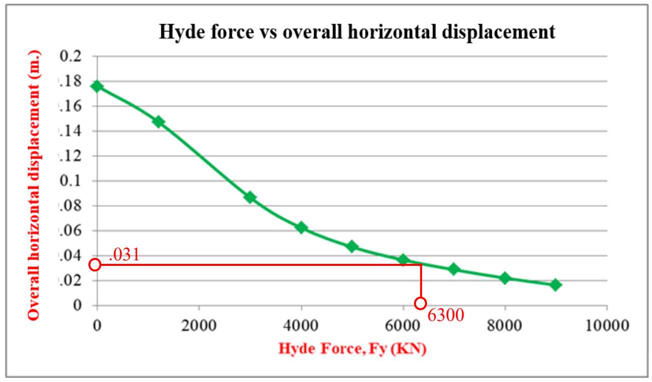


Figure 10 Design curve of Hyde force vs overall horizontal displacement of structure

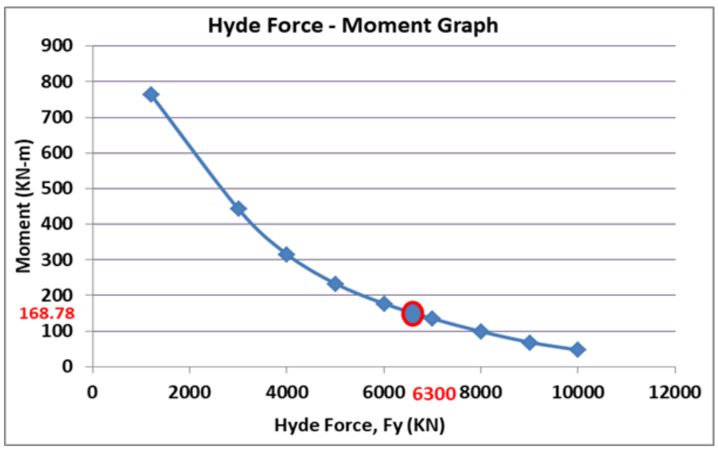


Figure 11 Design curve of Hyde force vs moment

3.2 Discussion

From the Figure 10 it can be observed that by the increment of HYDE device force, the overall horizontal displacement is reduced. Figure 11 shows the variation of moment against the increment of HYDE force. From this the HYDE design force is found as more or less 6300 kN which is determined against the design column maximum moment 168.78 kN. It is previously mentioned that the achieved moment against HYDE force should not exceed the maximum design moment of vertical load bearing members (column). So, if HYDE force is taken as 6300 kN from Figure 11 it is found that, the overall horizontal displacement is reduced to 0.031 m. from 0.176 m. (Figure 10) which is 80% reduction of displacement for this study case. According to Gleim and Dorka (2008) a well-designed HYDE force can dissipate up to 85% of the earthquake input energy.

Taking the HYDE design force as 6300 kN and using equation 3 the SPD size is determined as 270 mm. x 270 mm. x 10 mm. Where, the 270 mm. is both height and width for the SPD. 10 mm. is the thickness of web and flange. Yield stress for the shear panel is taken as 500 N/mm^2.

It is to be observed that, global bending which is alternating normal forces in the columns has a significant effect on the deformation in this case study. The storeys above the link in the ground floor are therefore not really rigid. That diminishes the effect of the HYDE-system with SP, since the SP works only on the global shear. This leads to a much larger SP-force than expected under more suitable situations. Provided that the elastic limit is intact, the application of the shear panel does have advantages even in this case (mainly damage control in the rest of the structure).

4.0 CONCLUSION

From the analysis it is achieved that the HYDE structural concept is very effective on structures having soft-story features and the system can significantly reduce the horizontal displacement of structure against earthquake thus increasing its structural performance. It is to be noted that, more than 35 mm. maximum deformations are required for the chosen shear panel and should be verified by cyclic experiments as a quality control measure. And particular care must be taken in designing the connection to the existing building, which must transfer the required HYDE design force (in this case 6300 kN) safely. Without these considerations, the proper functioning of the Hyde System cannot be assured.

According to a study by Comprehensive Disaster Management Program (CDMP 2009), the unplanned and congested structural construction of the major cities of Bangladesh will be highly affected against moderate to strong earthquake. That is why structural engineers are in search of a reliable seismic protection system for long to protect the existing medium rise RC buildings with soft ground floor. To help their effort this study is performed and a mathematical application of HYsteretic DEvice (HYDE) seismic protection system is presented on an existing five storey residential building.

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