Seismic analysis of steel diagrid structures using Triple Friction Pendulum Isloator (TFP)

Althaf Hyder P. R. and Amritha E. K.

Abstract— Today new technique of construction as well as aspect of design is coming to forefront as method of conventional design has failed to give the proper result. Base isolation is one of the most widely accepted seismic protection system used in earthquake prone areas. The base isolation system separates the structure from its foundation and primary moves it relate to that of the super structure. Diagrid structure is new trending concept in the field of structural engineering taking into account the factors of structural stability, aesthetic appearance and economic consideration. The scope of the paper is related to the seismic analysis of steel di-agrid structure in combination with base isolation. Here Triple Friction Pendulum Isolator is used for base isolation. Dynamic linear response spectrum analysis and dynamic linear time history analysis is performed in the isolated diagrid building. Further a comparative study of performance of base isolated diagrid building has been carried out by response spectrum and time history analysis by changing the bracings and bracing arrangement pattern. ie, X, V, inverted V, eccen forward and eccen backward bracings in whole, alternate, horizontal and vertical pattern ar-rangemets. For this a 22 storey and 11 storey steel diagrid building is designed and the above mentioned analysis is carried out. Base shear and top storey displace-ment are used as parameters for this study. From the results it concluded that for both 22 storey and 11 storey diagrid building, building having V bracing with al-ternate arrangement pattern showing better results.

Keywords- Diagrid structure, Base isolation, Triple Friction Pendulum Isolator, Bracing arrangement pattern, Response spectrum analysis, Time history analysis

1 Introduction

Earthquake can be defined as a process where there is sudden release of stress waves and large amount of energy due to violent tremor caused to earth's crust. Severity of earthquake depends upon the amount of energy released. Size and type of rup-ture area also influence the magnitude of an earthquake. Effects of an earth-quake depend on factors like rock and soil media through which the wave propa-gates. Damages caused by an earthquake is further dependent on site conditions such as characteristics of soil, ground conditions, water table and topography etc. Vibration mitigation should be done to overcome the problems caused by seismic excitation. This could be done by modifying structural mass, stiffness and inherent damping of structures. Tuned mass damper (TMD) is a device which could be used to control vibrations by varying above mentioned parameters. It consists of mass element, a spring element to modify the stiffness and damping element to dissipate vibrations

Sudden release of stored energy in earth's crust leads to destruction of natural en-vironment as well as manmade infrastructure; it also causes loss of life and mon-ey. Hence to avoid these problems proper mitigation techniques should be adopt-ed. Earthquake effect mitigation can be achieved by proper seismic studies and analysis. Adopting suitable retrofitting techniques after these studies help to re-duce damage caused during an earthquake.

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Two different load types considered during a seismic analysis of a structure are static and dynamic loads, static loads does not vary with respect to time whereas dynamic loads are time varying. Due to rapid industrialization and urbanization tall lighter structures are constructed around the world. As the height of the struc-ture increases they become more flexible and slender. Low inherent damping of building makes the structure more prone to vibrations under dynamic loads. Dynamic loading are sometimes neglected during design process due to its complexi-ty, this in turn leads to sever damage to the structure during an earthquake. Struc-tural stiffness and durability is affected by Periodic dynamic loading. Resonance occurs if frequency of vibration coincides with structure's natural frequency, lead-ing to total collapse of structure.

A Diagonal Grid or Diagrid Structure is a framework of diagonally intersecting section (steel section used in this paper) that is used in the construction of sky-scrapers buildings and rooftops. These structures offer unique supremacy to high risers because of structural efficiency and pleasant aesthetics. It conveniently eliminates the dependence on column of a structure and also requires compara-tively lesser structural steel and thus optimize the cost. The Steel Diagrid Structure are more popular than other conventional materials such as wooden beams and concrete as they are quickly erected. These buildings are energy efficient, envi-ronmentally sensitive and a clear winner in the run for what future sustainable buildings may look like.

Base isolation is one of the most widely accepted seismic protection system used in building in Earthquake prone areas. The base isolation system separates the structures from its foundation and primarily moves it relative to that of the super structure. The scope of the paper is related to the seismic analysis of steel diagrid structure in combination with base isolation. Here Triple Friction Pendu-lum Isolator is used for base isolation. Dynamic linear response spectrum analysis and dynamic linear time history analysis is performed in the isolated diagrid build-ing. Further a comparative study of performance of base isolated diagrid building has been carried out by response spectrum and time history analysis by changing the bracings and bracing arrangement pattern. Base shear and top storey dis-placement are used as parameters for this study.

FIGURE 1. A TYPICAL DIAGRID STRUCTURE (8)

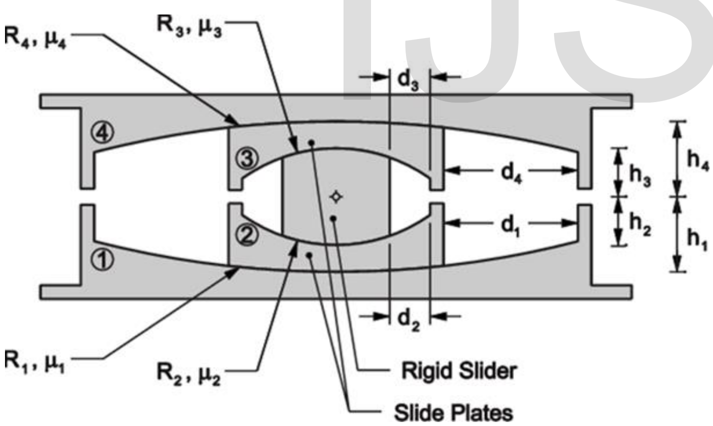


FIGURE 2. CROSS SECTION OF TFP (9)

2 OBJECTIVES AND SCOPE

- Diagrid structures are efficient in lateral load resistance and esthetic effect and TFP is cost efficient isolator and good energy dissipater, so combining these two will expected give good seismic resistance
- For this, selected two types of steel buildings, one short building (11 storey) and one tall building (22 storey) based on the specified height to width ratio of base isolated building
- Provided different types bracing, namely X, V, Invert-ed V, Eccen for-ward and Eccen backward ect. in different arrangement pattern namely Whole, Alternate, Horizontal and Vertical ect. in these build-ing and made the building diagrid structure
- Provided TFP isolator in these diagrid structures based on total load coming on the base
- Done seismic analysis in these structures
- Compared the results and find out which type of diagrid structure providing maximum earthquake resistance in the application of TFP

TABLE 1. SIZE OF TYPICAL MEMBERS OF 22 AND 11 STOREY DIAGRID STRUCTURES

Storey	Diagonal bracing sections	Interior column sections	Beam sections
22 storey	375mm Pipe sections with 12 mm thick	ISMB 500	ISMB 600
11 storey	375mm Pipe sections with 12 mm thick	ISMB 225	ISMB 200

3 ANALYSIS AND DESIGN OF 22 STOREY DIAGRID SYSTEM AND PROPERTIES OF TFP ISOLATOR

3.1 Building Configuration

In structures different types of bracings namely X, V, inverted V, eccen forward and eccen backward are given and made the structure diagrid. The angle of inclination is kept uniform throughout the height. The 22 sto-rey tall diagrid buildings are having 24 m × 24 m plan dimension. The storey height is 3.5 m. The typical plan and elevations are shown in Figure 3, Figure 4, Figure 5, Figure 6,Figure 7 and Figure 8 respectively. The interior frame of the dia-grid structures is designed only for gravity load. The live loads on floor slab are 3 kN/m2 and dead loads are auto generated by software. The dynamic along wind loading is computed based on the basic wind speed of 55 m/sec and terrain cate-gory IV as per IS:875 (III)-1987.

The design earthquake load is computed based on the zone factor of 0.36, medium soil, importance factor of 1 and response reduction factor of 4 (IS: 1893 (Part-I), 2002). Modeling, analysis and design of diagrid structure are carried out using ETABS software (ETABS 2015). For linear static and dynamic analysis by time history and response spectrum method the beams and columns are modeled by flexural elements and braces are modeled by truss elements. The support con-ditions are assumed as hinged. All structural members are designed using IS 800:2007. Secondary effect like temperature variation is not considered in the de-sign, assuming small variation in inside and outside temperature.

3.2 Datas used for time history anaalysis and response spectrum analysis of 22 storey diagrid strucure

Dead load - auto generated by software
Live load - 3 kN/m²

Seismic coefficients (as per IS 1893)

R (response reduction factor) - 4
Z (zone factor) - 0.36
I (importance factor) - 1

Wind coefficients (as per IS 875 (part 3))

Cp (wind ward coefficient) - 0.8
Cp (leeward coefficient) - 0.5
K1 (risk coefficient) - 1
K3 (topography factor) - 1

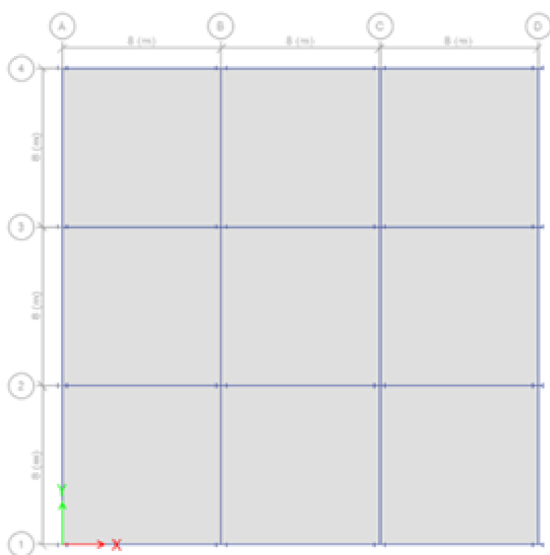


FIGURE 3. TYPICAL PLAN COMMON TO ALL 22 STOREY DIAGRID BUILDING

GRAPH

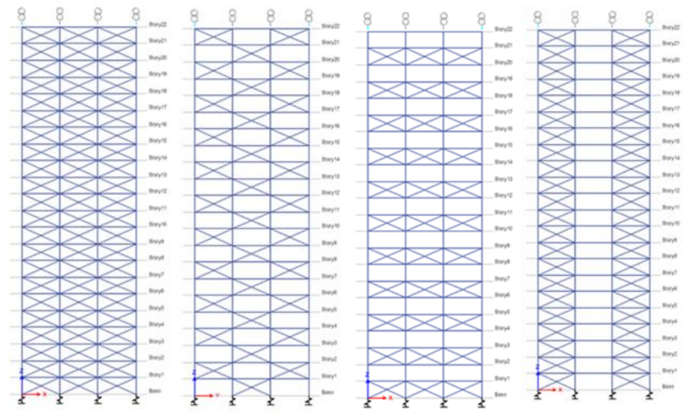


FIGURE 4. ELEVATION OF 22 STOREY DIAGRID BUILDINGS WITH X BRACING PATTERN ARRANGEMENT ((A) WHOLE, (B) ALTERNATE, (C) HORIZONTAL, (D) VERTICAL)

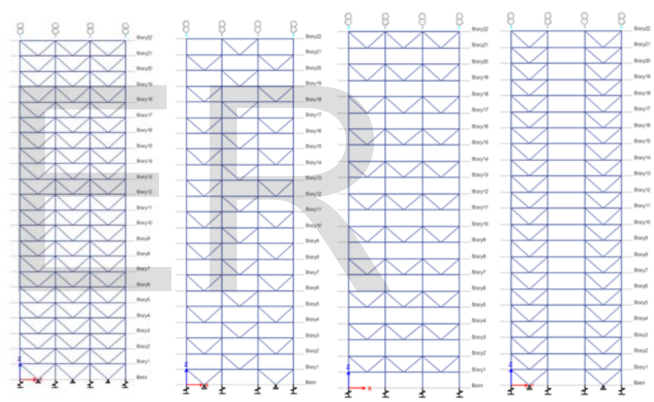


FIGURE 5. ELEVATION OF 22 STOREY DIAGRID BUILDINGS WITH V BRACING PATTERN ARRANGEMENT ((A) WHOLE, (B) ALTERNATE, (C) HORIZONTAL, (D) VERTICAL)

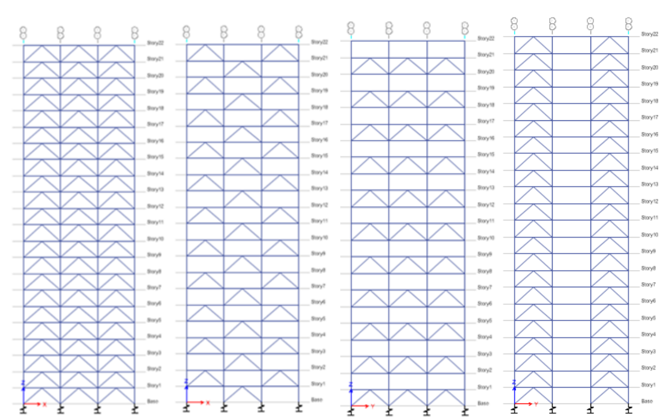


FIGURE 6. ELEVATION OF 22 STOREY DIAGRID BUILDINGS WITH INVERTED V BRACING PATTERN ARRANGEMENT ((A) WHOLE, (B) ALTERNATE, (C) HORIZONTAL, (D) VERTICAL)

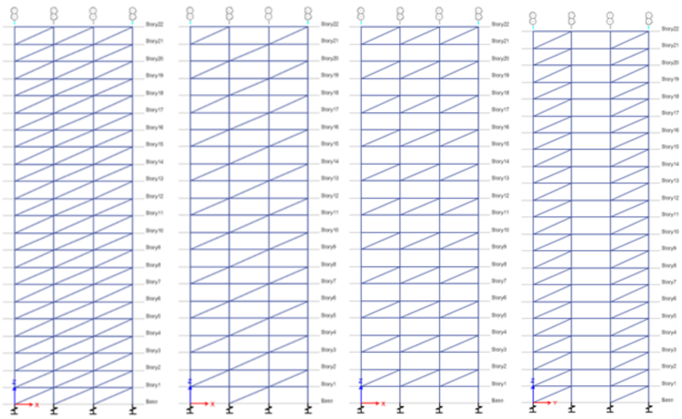


FIGURE 7. ELEVATION OF 22 STOREY DIAGRID BUILDINGS WITH ECCEN FORWARD BRAC-ING PATTERN ARRANGEMENT ((A) WHOLE, (B) ALTERNATE, (C) HORIZONTAL, (D) VERTICAL)

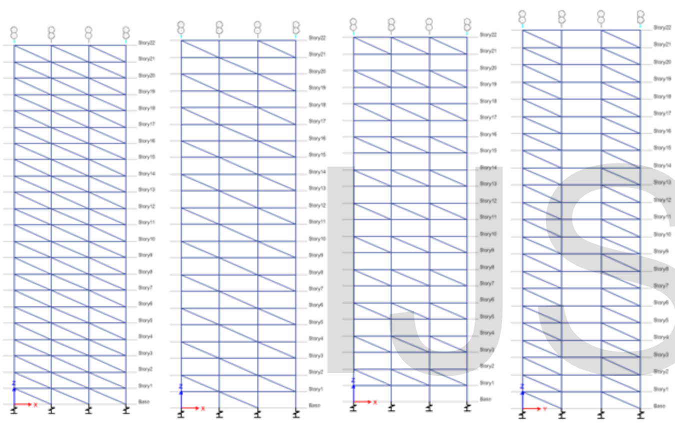


FIGURE 8. ELEVATION OF 22 STOREY DIAGRID BUILDINGS WITH ECCEN BACKWARD BRACING PATTERN ARRANGEMENT ((A) WHOLE, (B) ALTERNATE, (C) HORIZONTAL, (D) VERTI-CAL)

3.3 Properties of TFP isolator:

Table 2. Isolation bearing properties

Geometric Properties		Frictional Properties	
Property	Value (mm)	Property	Value
$R_{1eff} = R_{4eff}$	2133	$\mu_1 = \mu_4$ Lower bound	0.067
$R_{2eff} = R_{3eff}$	330	$\mu_2 = \mu_3$ Lower bound	0.212
$d_{1^*} = d_{4^*}$	339.8	μ Lower bound	0.045
$d_{2^*} = d_{3^*}$	41.5	$\mu_1 = \mu_4$ upper bound	0.080
		$\mu_2 = \mu_3$ upper bound	0.254
		μ upper bound	0.053

Where,

R_{1eff}, R_{4eff} - effective radii of outer regimes

R_{2eff}, R_{3eff} - effective radii of inner regimes

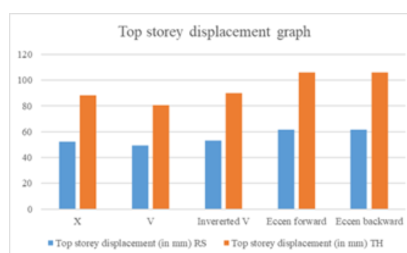
$\mu 1$, $\mu 4$ -coefficient of dynamic frictions of outer re-gimes

$\mu 2$, $\mu 3$ - coefficient of dynamic frictions of outer re-gimes

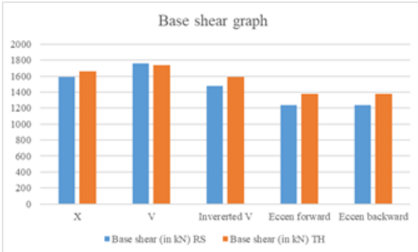
The above mentioned TFP isolator was kept on the base of the 22 storey diagrid building and analysis was done by dynamic linear time history and dynamic linear response spectrum analysis.

3.4 Analysis results of 22 storey buildings with TFP isolator

The analysis results in terms of top storey displacement and base shear are pre-sented in this section. From the analysis diagrid structure with alternate bracing pattern showing bet-ter results. Figure 9 shows the top storey displacement and base shear comparison graph of 22 storey diagrid structures with alternate bracing pattern respectively.



(a)



(b)

FIGURE 9. TOP STOREY DISPLACEMENT AND BASE SHEAR COMPARISON GRAPH OF 22 STOREY DIAGRID STRUCTURES WITH ALTERNATE BRACING PATTERN (RS – BY RESPONSE SPECTRUM ANALYSIS, TH – BY TIME HISTORY)

4 ANALYSIS AND DESIGN OF 11 STOREY DIA-GRID SYSTEM AND PROPERTIES OF TFP ISOLATOR

4.1 Building Configuration

Except plan, elevation and building components rest of the properties are same to 11 storey diagrid buildings as compared to 22 storey diagrid buildings. The 11 sto-rey tall diagrid buildings are having 12 m × 12 m plan dimension. The storey height is 3.5 m. The typical plan of the building is shown in Figure 10. The brac-ings used and bracing pattern arrange-ments are as same as done in 22 storey dia-grid building.

4.2 Datas used for time history analaysis and response spectrum analysis of 22 storey diagrid strucure

Dead load - auto generated by software

Live load - 3 kN/m²

Seismic coefficients (as per IS 1893)

R (response reduction factor) - 4
Z (zone factor) - 0.36
I (importance factor) - 1

Wind coefficients (as per IS 875 (part 3))

Cp (wind ward coefficient) - 0.8
Cp (leeward coefficient) - 0.5
K1 (risk coefficient) - 1
K3 (topography factor) - 1

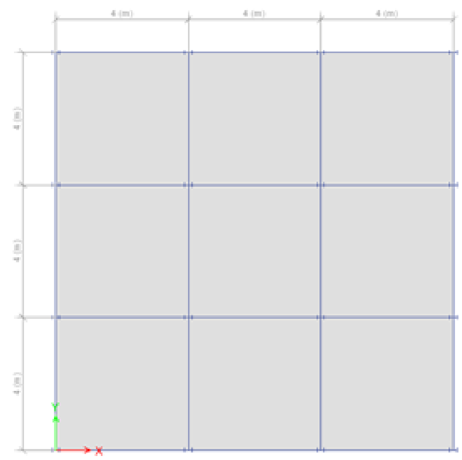


FIGURE 10. TYPICAL PLAN COMMON TO ALL 11 STOREY DIA-GRID BUILDING

4.3 Properties of TFP isolator

TABLE 3. ISOLATION BEARING PROPERTIES

Geometric Properties		Frictional Properties	
Property	Value (mm)	Property	Value
$R_{1eff} = R_{4eff}$	3395	$\mu_1 = \mu_4$ Lower bound	0.078
$R_{2eff} = R_{3eff}$	526	$\mu_2 = \mu_3$ Lower bound	0.066
$d_{1*} = d_{4*}$	540.40	μ Lower bound	0.076
$d_{2*} = d_{3*}$	65.90	$\mu_1 = \mu_4$ upper bound	0.093
		$\mu_2 = \mu_3$ upper bound	0.080
		μ upper bound	0.091

Where,

R_{1eff}, R_{4eff} - effective radii of outer regimes

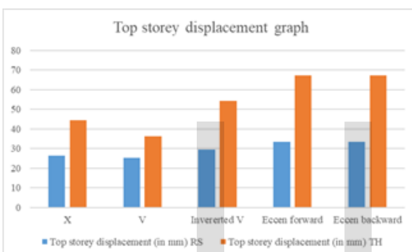
R_{2eff}, R_{3eff} - effective radii of inner regimes

$\mu 1$, $\mu 4$ -coefficient of dynamic frictions of outer regimes μ2, μ3 - coefficient of dynamic frictions of outer regimes

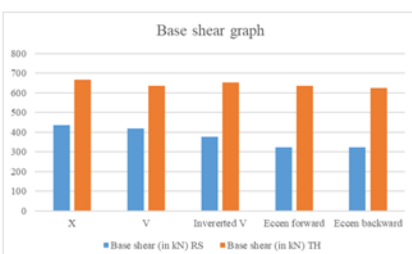
The above mentioned TFP isolator was kept on the base of the 11 storey diagrid building and analysis was done by dynamic linear time history and dynamic linear response spectrum analysis**.**

4.4 Analysis results of 11 storey buildings with TFP isolator

The analysis results in terms of top storey displacement and base shear are pre-sented in this section. From the analysis diagrid structure with alternate bracing pattern showing better results. Figure 11 shows the top storey displacement and base shear comparison graph of 11 storey diagrid structures with alternate bracing pattern respectively.



(A)



(B)

FIGURE 11. TOP STOREY DISPLACEMENT AND BASE SHEAR COMPARISON GRAPH OF 11 STOREY DIAGRID STRUCTURES WITH ALTERNATE BRACING PATTERN (RS – BY RESPONSE SPECTRUM ANALYSIS, TH – BY TIME HISTORY)

5 CONCLUSIONS

Based on study carried out in this paper following conclusions are derived for dia-grid structural system with TFP:

- From the analysis, for both 22 and 11 storey buildings V bracing with al-ternate arrangement pattern showing better results
- Increase of slope of braces increases the shear lag effect and lateral strength in diagrid structures
- The TFP found to be excellent seismic control device for the diagrid structures having incomplete module in frames in controlling forced re-sponses

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