

Geometric Design Steps of the Upper Toggle-Brace-Damper System

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Abstract: *The design procuress for toggle-brace-damper system is to complex. Particularly for those engineers who not have any much experiences in this area. In this paper, a comprehensive economic geometric design steps of the novel toggle-brace-damper system to enhance in new or retrofit existing structure is presented. Nonlinear time history analyses are carried out in Opensees.*

Keywords: Toggle-brace-damper; Energy dissipation; Magnification factor; Geometric design steps; Nonlinear time history analysis.

Introduction

In this paper, the study focuses on the preliminary geometric design steps in steel structure with toggle-brace-damper systems. Passive energy dissipation system to improve the performance of structure during earthquake was proposed a century ago. In the last few decades, significant research and development has been made to make structures safer and more robust in the event of an earthquake. The structure have been successfully designed and built using energy dissipation system in recent years, especially advantages have been present when retrofitting existing structures.

In last few years, a great deal of promise for engineering application in both analytical and experimental studies for toggle-brace-damper system has been presented. Constantinou et al have done some research of toggle systems examples [1] in 2001. Various toggle systems have been enhanced in the structures. A lower and upper toggle-brace-damper system with a fluid linear viscous device is directly connected to the beam in the structure and also with a 90 degree angle between one of the brace and the damper. Future, Hwang et al[2] have developed the lower and upper toggle systems to enhance to the connection of the beam-column structure in 2005. However, those toggle-brace-damper systems design affect the space for use.Chan. et al developed a new configuration of upper toggle-brace-damper system enhanced into a steel “soft-storey” structure [3] and retrofit of reinforced concrete structure[4].

In this paper, difference geometry scale factors have been evaluated for use with the viscous damper in parameters studies. The results shows that the magnification factor f of the toggle-brace-damper systems is highly dependent on the choice of the angle between beam to the leg of brace, the length of brace and length to width scale. Series of parameter studies had been done. Results demonstrated that the novel upper toggle-brace-damper system geometry size selects from the parameters studies can achieve a good performance level. And it is much better than chevron and diagonal. Also, this novel upper toggle-brace-damper system has at least 51% of using space and 21% material less than the other toggle-brace-damper system.

The displacement and drift angle of the structure are reduced significantly, as shown by the result values of the performance criteria. The purpose of this paper is to present a geometric design steps that to design a new or retrofit existing structure. Case studies are presented to verify the accuracy of the proposed method in Opensees.

Novel Upper Toggle-Brace-Damper System

A toggle-brace-damper system main purpose is to magnify the displacement travelled in a damper. The configuration has been investigated by a number of researchers and application in the world has been reported. Anovel upper toggle-brace-damper system configuration presented in this paper is shown in Fig 1. Height and span is h and b . Two identical frames called lower brace l_1 and upper brace l_2 . The angle between lower brace and ground is θ_1 . θ_2 is the angle between upper brace leg l_2 and column and it can be determine from l_1 , h , b and θ_1 . Assuming the brace elements are axially stiff, the damper and the braces connection will move the change in axial deformation of damper u_D can be determined from θ_1 , θ_2 and horizontal story drift u .

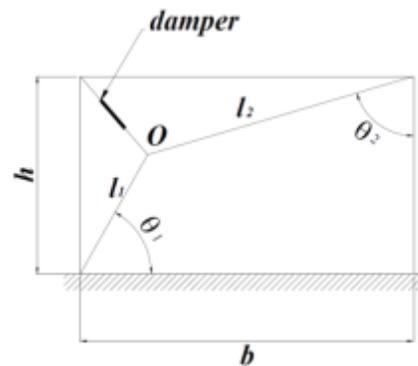


Figure 1 The Toggle-Brace-Damper configurations

The magnification factor f is defined as the ratio between the change in damper length and the horizontal displacement superstructure with respect to the ground. The relationship of magnification factor f in upper toggle-brace-damper system is showing below[8]:

$$F = f F_D \quad (1)$$

where F is the axial force, F_D is damper force and f is magnification factor:

$$u_D = f u \quad (2)$$

Where u_D is axial deformation of damper and u is interstory drift. Combination with the above Eq. (1) and Eq.(2), the magnification factor f can be defined by:

$$f = \frac{F}{F_D} = \frac{u_D}{u} \quad (3)$$

As showing in Fig 1 and governing all the calculations. The relationship between axial deformation of damper u_D and interstorey drift u as follow: where can be presented by:

$$u_D = \left(\frac{\cos \theta_1}{-\cos(\theta_1 + \theta_2)} \right) u \quad (4)$$

where θ_2 can be replaced by:

$$\theta_2 = \tan^{-1} \left(\frac{b - l_1 \cos \theta_1}{h - l_1 \sin \theta_1} \right) \quad (5)$$

Governing all the equations and simplify them, the magnification factor f corresponding to this upper toggle-brace-damper system is derived as follow:

$$f = \frac{\cos \theta_1}{-\cos \left[\theta_1 + \tan^{-1} \left(\frac{\frac{b - l_1 \cos \theta_1}{h - l_1 \sin \theta_1}}{1 - \frac{l_1}{h} \sin \theta_1} \right) \right]} \quad (6)$$

From equation (6), it is easy to find that the magnification factor f adopted in this study is affected by the geometry h , b , l_1 and θ_1 .

Parameter Study by Nonlinear Time History Analysis

As shown in equation (6), four parameters lower brace length l_1 , storey height h , span b and angle θ_1 will affect the magnification factor f . While h and b are normally determined by building geometry, l_1 and θ_1 are freely selected by design engineer. As a result, the parameters being studied are b/h ratio, l_1/h ratio and angle θ_1 . Table 1 lists the numerical values being analyzed.

To study the dynamic behaviour of a soft-storey steel structure with an upper toggle-brace-damper system, a parametric study is performed using nonlinear time-history analysis. Nonlinear time history analysis is carried out in OpenSees. OpenSees is a software framework for developing applications to simulate the performance of structural and geotechnical systems subjected to earthquakes. Four historical ground histories are selected from PEER Strong Motion Database. All time histories are selected from classification corresponds to clay or soft soil. Table 2 shows the history details.[12]

Table 1: Values of parametric studies

Parameter	Values
l_1/h ratio	0.1-1.2
b/h ratio	0.35, 0.55 and 0.75
Angle θ_1	45°-55°

Table 2: Ground Motion Records

Name	Peak Accel. [g]	Peak Vel. [cm/s]	Peak Displ. [cm]
Imperial Valley 1979	0.266	46.8	18.92
Chi-Chi, Taiwan 1999	0.18	67.5	40.97
Kobe 1995	0.611	127.1	35.77
Loma Prieta 1989	0.274	53.6	12.68

Effect of b/h ratio

The effect of b/h ratio on the magnification factor can be illustrated from Fig 2 (a), (b), and (c). Three b/h ratio,

angle l_1/h ratio and magnification factor f have been presented. Increases of b/h ratio tend to decrease the magnification factor f . Inspecting the figures, the ratio of b/h is determined by architecture or existing building, smaller l_1/h ratio and angle will have a higher magnification factor f , which means smaller maximum displacement.

The figures below are presented the relationship between different b/h ratios, l_1/h and angle θ_1 . Once the ratio of b/h is determined, l_1/h and θ_1 can be selected in this figure along with the ratio l_1/h . Then the magnification factor f can be easy to estimate from the figure without any calculation.

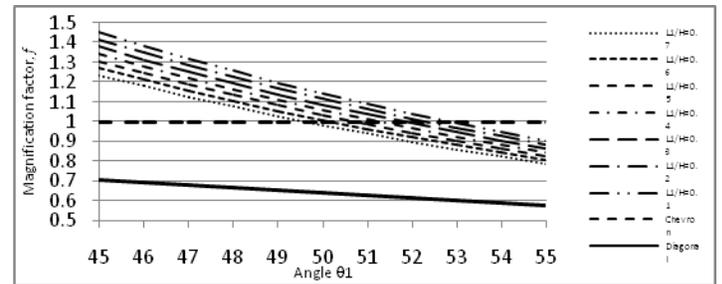


Figure 2(a): $b/h=20/7$, relationship between l_1/h and angle θ_1

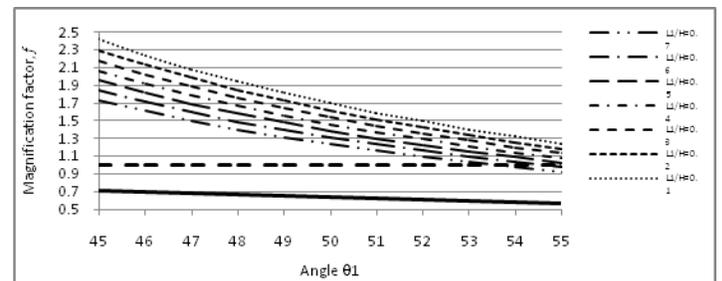


Figure 2(b): $b/h=20/11$, relationship between l_1/h and angle θ_1

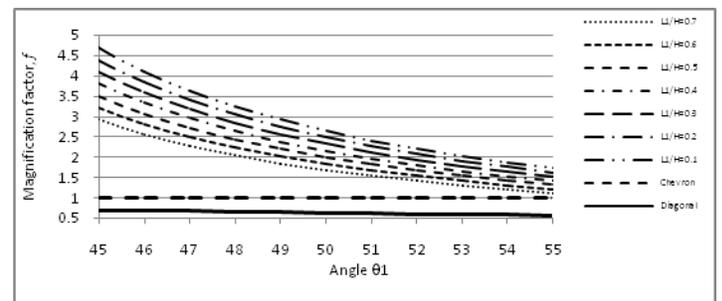


Figure 2(c): $b/h=20/15$, relationship between l_1/h and angle θ_1

Effect of l_1/h ratio

Effect of l_1/h ratio to displacement is plotted on Fig 4. The displacement tends to increase with an l_1/h ratio increase. The displacement is not responsive when l_1/h ratio located in between 0.1 to 0.5. However, it significantly increases once ratio reach 0.9, where displacement sudden up about 40%. If the storey height h is a constant, a smaller l_1 can be selected from the design engineer to reduce storey displacement. It appears that l_1/h ratio in between 0.1 to 0.9 is a reasonable choice.

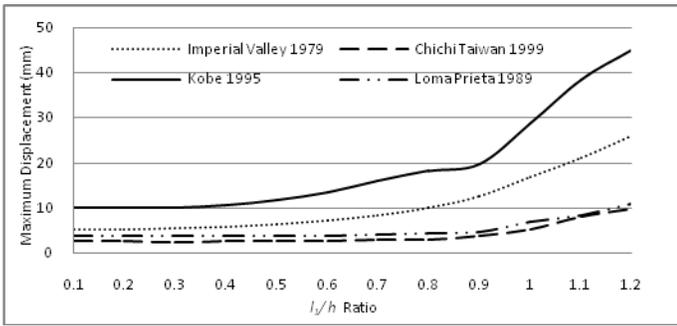


Figure 3: Relationship between maximum displacement and l_1/h ratio

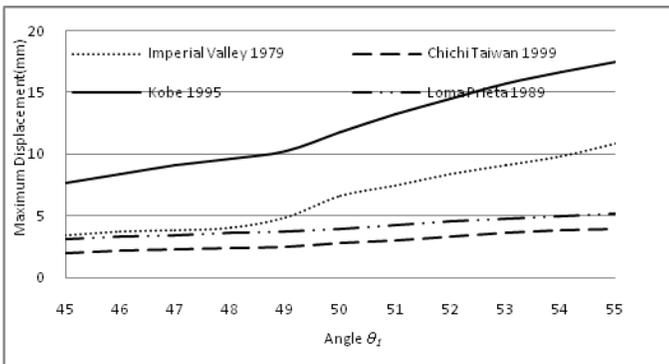


Figure 4: Effect of θ_1 on maximum storey displacement

Effect of angle θ_1

The effect of angle θ_1 and maximum storey displacement is illustrated in Figure 5. The range of θ_1 studied is between 45° to 55° . As the angle θ_1 increases, the maximum storey displacement also increases. Once θ_1 approaches 50° , storey displacement tends to increase more rapidly. Base on numerical experiments, the optimum selection of angle θ_1 is in between 45° to 50° .

Simply Geometry Design Step

A design step, base of the height h and span b , to compute the magnification factor f and the size of toggle bracing design is presented. These ratios affect the magnification factor and thus maximum storey displacement. The magnification factor f can be estimated without calculation. The design step, which takes into account the soft-stories structure, is summarized below:

- 1) Determined the structure story height h and span b/h ratio. Then select the b/h ratio figure. (i.e. Fig.2 (a), (b),(c))
- 2) Base from the figure, choose a toggle lower arc leg to story height l_1/h ratio and the angle θ_1 .
- 3) Easy to get the magnification factor f from the figure without any calculation.

This parameter studies shows that the proposed design step can predict and easy to find out the magnification factor f . Even though, for the engineer without any experience to design a seismic energy dissipation system. Only three steps, the performing of this novel toggle-bracing system can be estimated.

Case Study

Base on the previous design step, the optimum setup of the toggle brace system Fig 5 (a) and a diagonal brace system Fig 5(b) are been chosen to enhance into a 3 and 6 storey steel frame structures. To illustrate the effect of toggle damper-brace systems, consider an existing building under soft-storey mechanism. The performance of structure can be evaluated in various earthquake records to analysis. Ground motion records from Table 2 with a reasonable scale has successfully completed in Opensees.

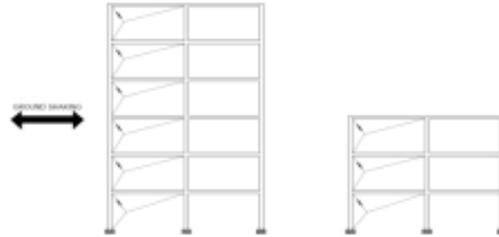


Figure 5(a) Steel structures with toggle bracing

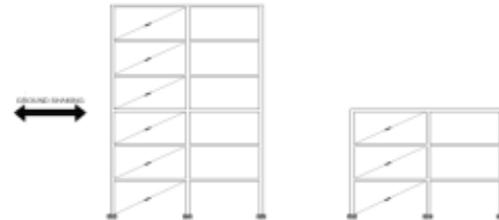
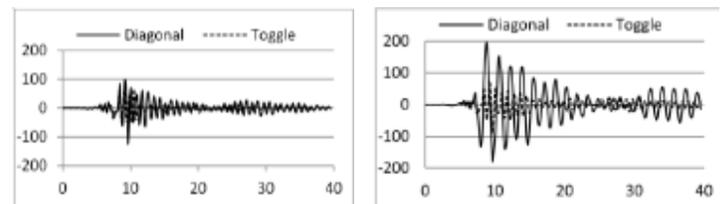


Figure 5 (b) Steel structures with

For illustrative purpose, a single direction ground motion is applied. Nonlinear time history analysis is implemented by numerical integration on Opensees. Fig 6(a) and (b) shows the maximum displacement comparison for two structures. Fig 7 shows the interstorey drift for each storey. Results clearly assign out the toggle bracing is very effectively compared to the chevron and non-brace structure based on the simple design step show before. The maximum interstorey drift is reduced minimum 21% in 3 stories structure and 26% in 6 stories structure. Fig 8 is base shear vs. displacement graph. Fig 9 is the comparison base shear diagram with different earthquake record. The nonlinearity of base shear is a consequence of nonlinear damper. At the end of ground shaking, approximately 74% of input energy is diverted to the damper, while the remaining energy is dissipated through viscous damping. Maximum displacement of superstructure in level 6 is controlled within $1/152$ of height of columns.



120% Imperial Valley 1979

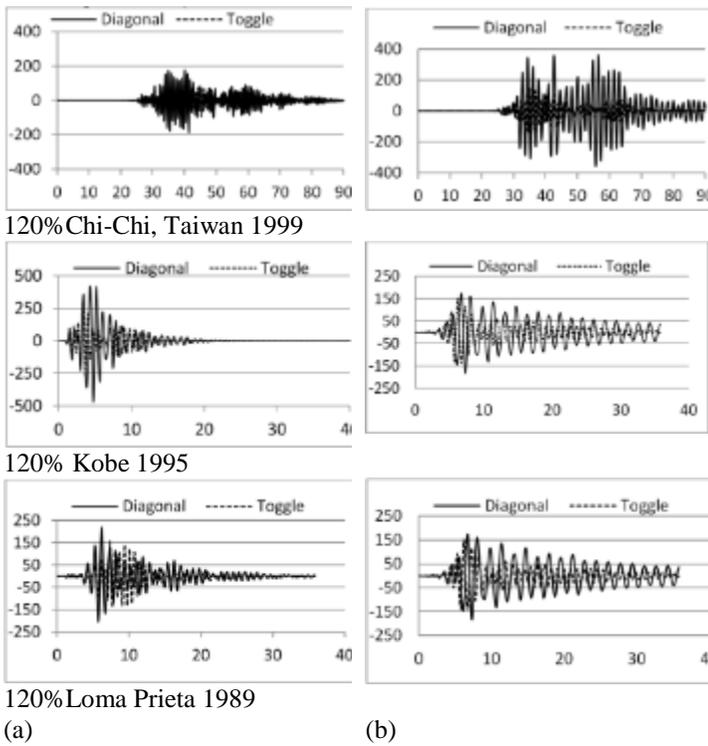
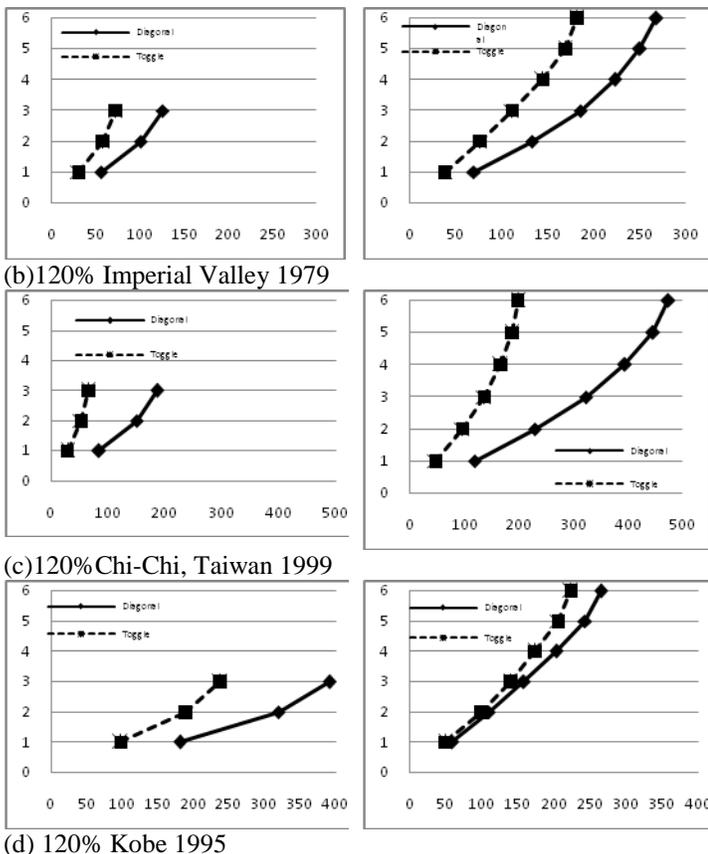


Figure 6(a) 3 stories structure maximum displacement;
6(b) 6 stories structure maximum displacement.
[Vertical axis: Displacement (mm); horizontal Axis: Time (Sec)]



(d) 120% Kobe 1995

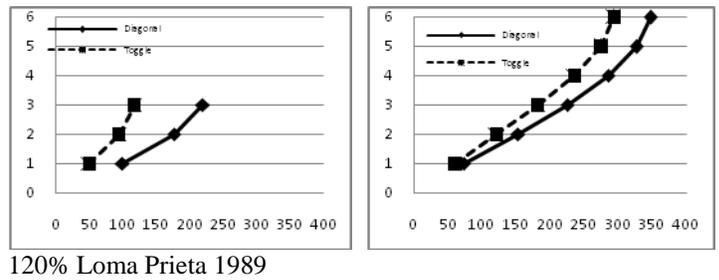


Figure 7 Inter drift displacement in 3 stories and 6 stories
[Vertical Axis: Story Horizontal Axis: Displacement (mm)]

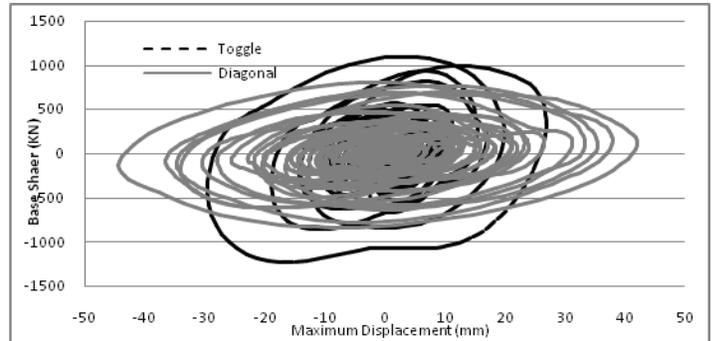


Figure 8 Base Shears vs. Displacement

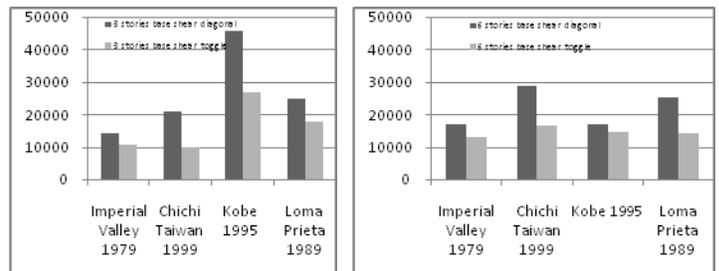


Figure 9 Base Shear Comparisons

Summary and conclusion

Base on the parameter studies and case studies in this paper a simple design step of a novel upper toggle-brace-damper system to design a new or retrofit in existing structure is presented. Governing equations including the magnification factor and lateral stiffness contributed by a toggle-brace-damper system are formulated. The relationship between magnification factor and the geometry of structure are determined. The optimal geometrical design of toggle-brace mechanism is discussed. Nonlinear time history analyses are carried out on selected brace configurations in Opensees. Results are presented in this study provide an insight into the preliminary selection of base structure geometric design. A simply design steps of the novel upper toggle bracing system to design or robust in steel structure in different types of soft soil is presented. The magnification factor can be simply to get base on the structural height and span. When the engineer design the toggle-brace-damper system, the lower brace arc length and angle between the lower arc and ground level can be easy to select from the graph. This paper investigates the use of toggle-brace system as a mitigation measure to the multi-level steel structure. Governing equations of such system are presented in this paper. A case study of two multi stories structures retrofitted

by addition of toggle-damper-braces analysis in Opensees successful to prove the design steps.

A design step, base of the height and span ratio, to compute the magnification factor and the size of toggle bracing design is presented. The magnification factor can be estimated without calculation. The design step, which takes into account the soft-stories structure, is summarized below:

- 1) Determined the structure story height h and span b/h ratio. Then select the b/h ratio figure. (i.e. Fig.2 (a), (b),(c))
- 2) Base from the figure, choose a toggle lower arc leg to story height l_j/h ratio and the angle θ_1 .
- 3) Easy to get the magnification factor f from the figure without any calculation.

In particular, a comprehensive economical design steps has been finally performed. The parameter studies shows that the proposed design step can predict and easy to find out the magnification factor. Even though, for the engineer without any experience to design a seismic energy dissipation system. Only three steps, the performing of this novel toggle-brace-damper system can be estimated. As future work, the effects of applying this toggle-brace-damper system on other types of structures will be investigated. This toggle-brace-damper system is expected to be an excellent solution for the existing and new building of economical way to installed it.

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