SEISMIC RESPONSE ANALYSES OF RC PORTAL FRAMES WITH LARGE DEFORMABLE ELASTIC BRACES

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ABSTRACT

Large deformable elastic braces (LDEBs) are devices which do never yield subject to large deformation under great earthquakes. In structures with LDEBs, elastic restoring force by LDEBs can improve seismic response under great earthquakes. In previous works, the effectiveness of LDEBs for the steel structures was confirmed by experimental tests and seismic response analyses. Here, the topology of LDEBs is determined by an optimization method, and seismic response analyses of RC portal frames with LDEBs are conducted. The effectiveness of LDEBs for the RC structures is discussed. RC portal frame are designed by Japanese seismic design code. LDEBs are equipped with the frame as knee braces. Seismic responses of not only the frame with LDEBs but also that without LDEBs are computed by dynamic nonlinear analysis software. In the analysis LDEBs are regarded as elastic bar elements. An input earthquake is JMA Kobe NS wave (1995 Kobe earthquakes). Hysteresis of story shear force and story drift, axial deformation of LDEBs, maximum and residual story drift are investigated. It is observed from computational results that LDEBs show remarkable improvements on maximum and residual story drifts of RC portal frame under a very large amplitude earthquake such as 1995 Kobe earthquake in Japan.

Keywords: an optimization method, large deformable elastic braces, RC frames, seismic response analyses.

1 INTRODUCTION

It is required for the seismic design in Japan that there are no damage under moderate earthquakes and no collapse under major earthquakes. Many buildings might experience a certain level of damage and deformation under major or great earthquakes. Recently various seismic control technologies [1–3] have been proposed. Especially, seismic upgradings by hysteresis dampers have been applied for many buildings in Japan. It is expected that elastic restoring force of a main frame and the hysteresis damping effect of the hysteresis damper reduce seismic response [4]. However, there are some posing problems for seismic upgrading design by hysteresis dampers. Firstly, increasing strength of the superstructure by seismic upgrading lead damage concentration of foundation structure under great earthquakes. Secondly, there is a possibility of plastic damage in main frame under great earthquakes. The plastic damage in main frame lead to large residual deformation because of lack of restoring force. Large deformable elastic braces (LDEBs) used in this study are devices which do never yield under great earthquakes [5]. It is expected that LDEBs realize reduction of seismic response with a slight increasing of strength of superstructure. This paper shows an example of morphogenesis of LDEBs by an optimization method. Moreover, seismic response analyses of portal RC frames with and without LDEBs are conducted, and the effectivenesses of LDEBs are discussed.

2 LARGE DEFORMABLE ELASTIC BRACES (LDEBS)

Figure 1 shows an example of large deformable elastic braces (LDEBs) [5]. This shape can realize large elastic deformation. It is confirmed from linear elastic FEM analysis subject to tensile load that yielding deformation and yielding force of the shape of Fig. 1 is 28.72 mm

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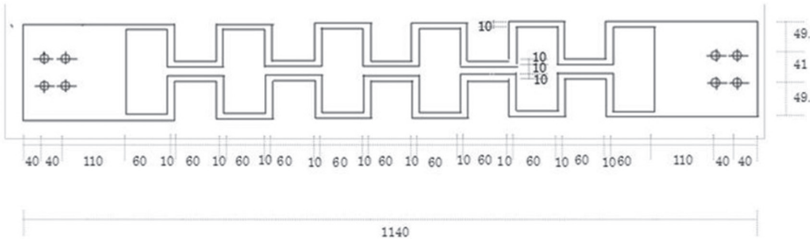


Figure 1: An example of LDEBs [5].

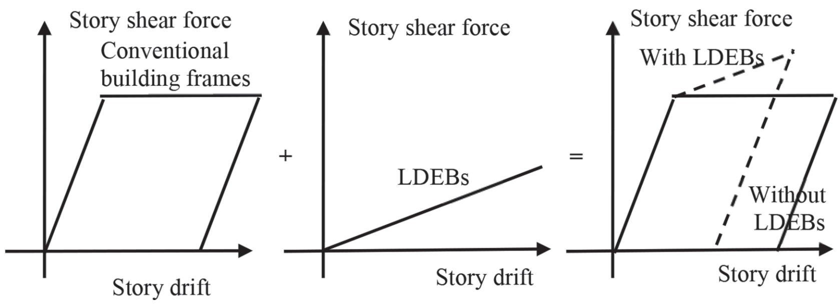


Figure 2: The relationship between story shear force and story drift of a conventional building frame and the frame with LDEBs.

and 15.20 kN, respectively. While seismic horizontal load–deformation relationship of conventional buildings are shown as Fig. 2, and that of buildings with LDEBs are shown as Fig. 3. It is expected that second stiffness by LDEBs can reduce maximum and residual story drift under major or great earthquakes. Here topology patterns of LDEBs with better performance than Fig. 1 are generated on a computer by an optimization method (genetic algorithm) as shown in the following section.

2.1 Topology optimization of LDEBs

A topology optimization problem for a plane stress two-dimensional plate is considered. An inverse Fourier transform function to represent the topological patterns of the plate is defined as follows.

$$F(x_k, y_k) = \sum_{u=-NFX}^{NFX} \sum_{v=-NFY}^{NFY} (a_{u,v} + b_{u,v} i) e^{i\pi(\gamma_1 u x_k / LX + \gamma_2 v y_k / LY)} , \tag{1}$$

where $u = -NFX, \ldots, -3, -2, -1, 1, 2, 3, \ldots, NFX$, $v = -NFY, \ldots, -3, -2, -1, 1, 2, 3, \ldots, NFY$, i represents an imaginary unit, e represents the Naperian base, and $a_{u,v}$ and $b_{u,v}$ are real-valued parameters to be computed in the optimization process, which are greater than –1 and less than 1. x_k and y_k represent x- and y-coordinates of the centre of the element k.

Since F should be a real function, the following complex conjugate conditions can be used.

$$a_{u,v} = a_{-u,-v},\ b_{u,v} = -b_{-u,-v}. \tag{2}$$

Each element is distinguished as either a solid or a void according to the value of F. If the value of F corresponding to the element k satisfies the following equation, the element k is a solid, otherwise it is a void.

$$F\min + MIN(\beta_1, \beta_2)\cdot(F\max - F\min) \leq F(x_k, y_k) \leq F\min + MAX(\beta_1, \beta_2)\cdot(F\max - F\min)\,, \quad (3)$$

where F_{max} and F_{min} represent the maximum and minimum values of F, respectively, over all the elements. β_1 and β_2 ($0 \leqq \beta_1 \leqq 1$, $0 \leqq \beta_2 \leqq 1$) represent parameters to be computed in the optimization process.

2.2 A formulation for topology optimization of LDEBs

A formulation for topology optimization of LDEBs can be formulated as follows.

Find $a_{u,v}$, $b_{u,v}$ and β_1 and β_2 which minimize

$$Z = 1/U + p[V/V0 + MAX\{0,(Uy-U0)/U0\} + MAX\{P/Py, Py/P\}], \quad (4)$$

where U represents the displacement by given load P, V represents the plate volume for the current topology, V0 represents the plate volume where all the elements are solid, Uy represents yielding displacement at loading point, U0 represents the critical value of U and Py represents yielding load. Von Mises is used as yielding condition of plate elements.

2.3 Numerical results

The above mentioned optimization problem for a 5488 (196×28) elements meshed plate under tensile load is solved by real coded genetic algorithm with heuristic crossover [6]. Young's modulus is 205 GPa. The thickness, the width and the length of the plate is 9 mm, 210 mm and 1470 mm, respectively. Poisson's ratio is 0.3. Critical displacement U0 is set to 80 mm. 29000N and 58000N are given as load P. The Young's modulus of the void element is set to 10^{-4} times that of the solid element. The number of individuals is 50, mutation probability is 0.05, and crossover probability is 1.0. NFX and NFY in eqn (1) are both 2. γ_1 and γ_2 in eqn (1) are 36 and 1, respectively. Figure 3 represents the optimum topology of LDEBs until 100 generations. It is shown that this optimization method can realize very large elastic deformation, 2% or 2.5% of the plate length.

Figure 3: (a) Optimum topology of LDEBs (P = 29000N, Py = 28600N, Uy = 41.2 mm).

Figure 3: (b) Optimum topology of LDEBs (P = 58000N, Py = 56900N, Uy = 32.1 mm).

3 SEISMIC RESPONSE ANALYSES

Figure 4 shows a detail of an RC portal frame using LDEBs as knee braces for seismic response analyses. Each LDEB is sandwiched by two channels using non tension bolt connection. 12 re-bars (22 mm) are allocated in the column sections whose height and width are both 500 mm, and 8 re-bars are allocated in the girder section whose depth and width are 550 mm and 400 mm, respectively. Yield strength, Young's modulus and strain hardening ratio of the re-bars are 400 N/mm^2, 200 GPa, 0.005, respectively, and bilinear hysteresis rule is applied. Compressive strength of concrete is 30 MPa, and Mander *et al.* nonlinear concrete model [7] is used. Here, time domain analyses of not only a computational model of an RC portal frame without LDEBs shown in Fig. 5a, but also that with LDEBs (Elastic bar elements, axial stiffness 3.76 kN/mm), shown in Fig. 5b are conducted. An input earthquake is JMA Kobe NS wave (1995 Kobe earthquake). Peak ground acceleration (PGA) and duration time of the wave for computation is 818(gal) and 29(sec.), respectively. Seismostruct [8] is used as time domain analysis software. In the software, the sectional stress-strain state of beam-column elements is obtained through the integration of the nonlinear uniaxial material response of the individual fibres [8]. Figures 6 and 7 show the time history of story drift and

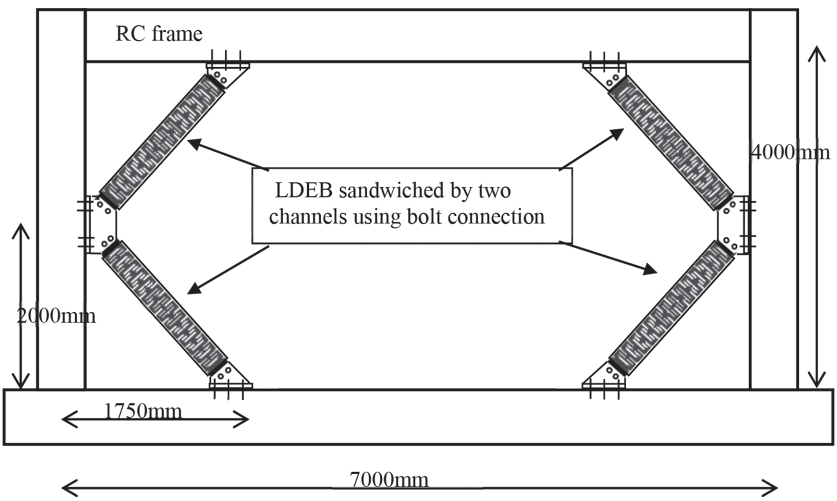
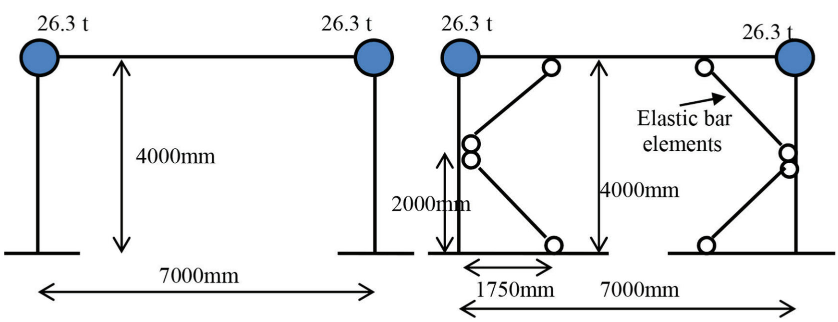


Figure 4: A detail of an RC portal frame with LDEBs.



(a) Without LDEBs (b) With LDEBs

Figure 5: Computational models of an RC portal frame without LDEBs and that with LDEBs.

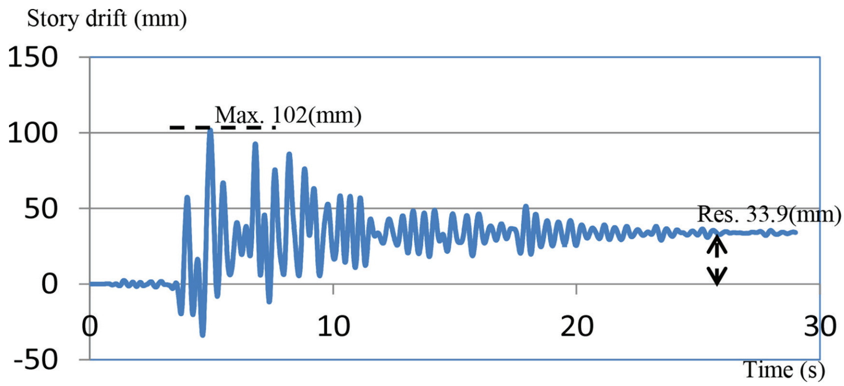


Figure 6: (a) Time history of story drift of the frame without LDEBs.

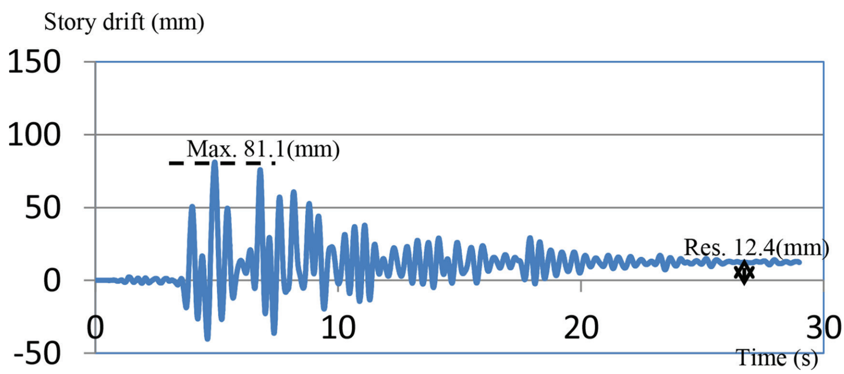


Figure 6: (b) Time history of story drift of the frame with LDEBs.

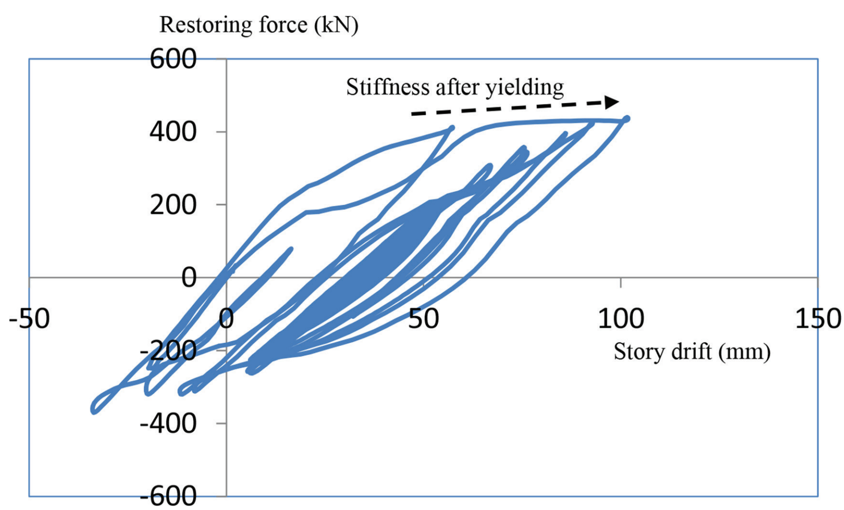


Figure 7: (a) The relationship between story restoring force and story drift of the frame without LDEBs.

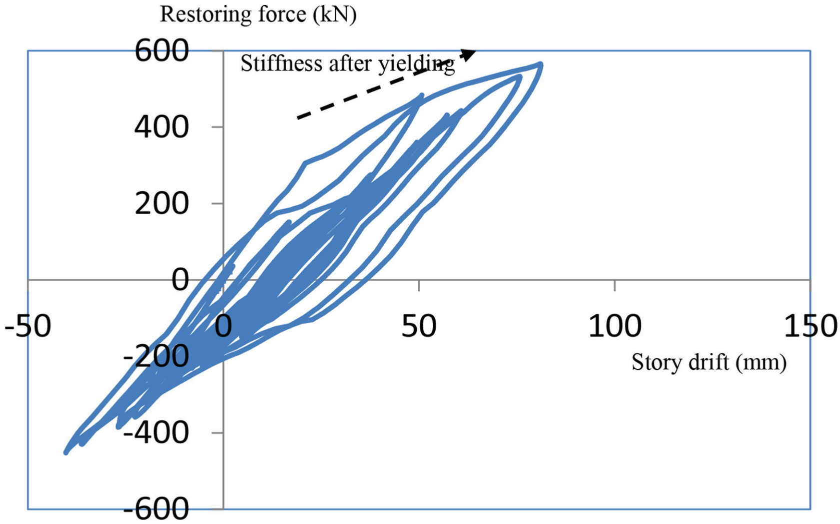


Figure 7: (b) The relationship between story restoring force and story drift of the frame with LDEBs.

the relationship between story restoring force and story drift obtained by time domain analysis. Broken arrows in these figures show that the RC frames with LDEBs have positive story stiffness after yielding to some extent, while the RC frame without LDEBs have just slight story stiffness after yielding. The maximum axial deformation of elastic bar elements was less than around 30 mm. It was also observed from these figures that LDEBs give improvements on maximum and residual story drifts.

4 CONCLUSIONS

This paper has shown an example of morphogenesis of Large Deformable Elastic Braces (LDEBs) by the optimization method. Moreover, seismic response analyses of portal RC frames with and without LDEBs have been conducted, and the effective-nesses of LDEBs have been discussed. Concluding remarks are as follows.

1. It has been shown that this optimization method presented here can realize very large elastic deformation, 2% or 2.5% of the plate length.
2. It has been observed from time domain analyses that LDEBs give improvements on maximum and residual story drifts for the RC portal frame.

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