A Uniform Storey Ductility Demand Seismic Design Method for Buildings

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ABSTRACT :

Based on direct displacement-based seismic design method, the target displacement profile is determined by the allowable uniform storey ductility. Only considering the first mode, reduce MDOF system equivalent SDOF system, the base shear is calculated based on the allowable storey ductility factor using inelastic displacement spectra. Then the base shear is distributed corresponding to the target displacement profile. This method is aim to make building's each storey ductility demand is similar under earthquakes, avoiding damage concentrated in one storey, making the seismic design of buildings economic and safe as far as possible.

KEYWORDS: seismic design, direct displacement based design, story ductility factor, inelastic displacement response spectra

1 INTRODUCTION

At present, only the maximum inter-storey drift is checked in seismic design, it means that if the maximum inter-storey drift is less code limit, then the building satisfying the seismic requirements. Experience in recent earthquakes has showed that only one storey was serious damaged or collapsed whenever the other storey were lightly damaged, it indicated that most earthquake energy dissipation concentrated in the soft storey. At same time that, if only control the maximum inter-storey drift in seismic design, without taking into account the relationship between all stories of displacement, it is likely caused soft storey damaged, Investment in the same circumstances, to reduce the structural seismic performance, increased probability of structural damage and the potential economic losses.

To overcome this problem, the need to propose a reasonable design method so that the design of the building has uniform storey ductility, and avoid earthquake damage concentrated in one storey. If use the current force-based design method to realize the uniform storey ductility demands, it will change the design of the complex and may require repeated iterative computing, greatly increasing the workload of design. So this paper proposed the uniform storey ductility demands seismic design method. Based on direct displacement-based design idea, according to the selected target displacement profile, the earthquake force is determined, with current design method, the design of structural members is completed.

2 PROPOSED THE SEISMIC DESIGN METHOD

In this paper, the life safety performance level was selected to be consistent with traditional design for life safety according to the Code for Seismic Design of Buildings (GB 50011-2001). Assuming the target storey ductility μ_f of all stories is same under very rare earthquakes.

Step1: determine the target displacement of design structure under very rare earthquake
For determined the geometry of the reinforced concrete frame structure, inter-storey yield drift can be determined as

$$\theta_{y,i} = 0.5\varepsilon_y l_{b,i} / h_{b,i} \tag{2.1}$$

Where $\theta_{y,i}$ is inter-storey yield drift, ε_y is yield strain of longitudinal reinforcement, $h_{b,i}$ is beam height, $l_{b,i}$ is beam bay length.
Structural Inter-storey drift under very rare earthquake is

$$\Delta u_{u,i} = h_i \theta_{y,i} \mu_f \qquad (2.2)$$

Where $\Delta u_{u,i}$ is the ith inter storey drift under very rare earthquake, h_i is story height.
Floor displacement under very rare earthquake is

$$u_i = \sum_{j=1}^{i} \Delta u_{u,j} \qquad i = 1,2,\cdots,n \qquad (2.3)$$

Where n is the number of the storey.

Step: 2 MDOF system is equivalent to SDOF system with the target displacement profile, only considering the first mode of structures.
The equivalent target displacement of the equivalent SDOF structure is

$$u_{sd} = \sum_{i=1}^{n} (m_i u_i^2) / \sum_{i=1}^{n} (m_i u_i) \qquad (2.4)$$

Where $\mathrm{m_i}$ is the mass of the ith storey.
The equivalent mass of the equivalent SDOF system is

$$\mathrm{m_e} = \frac{1}{u_{sd}} \sum_{i=1}^{n} (m_i u_i) \qquad (2.5)$$

Step:3 The effective period of the equivalent SDOF system is determined according to displacement spectra derived from acceleration spectra of China code and the equivalent target displacement of the equivalent SDOF system..

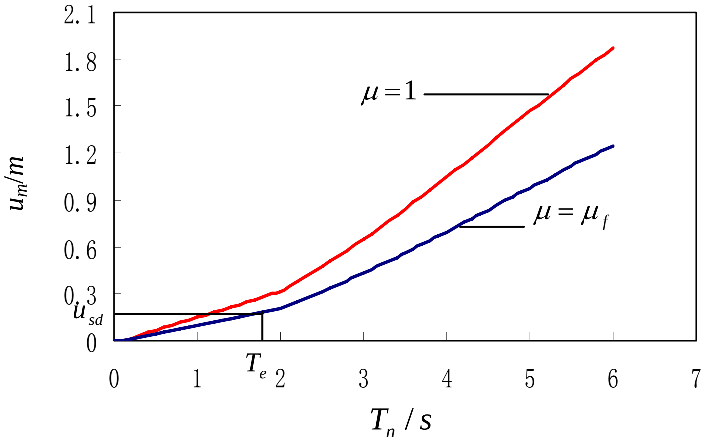


Figure 1 Displacement Spectra

The displacement spectra with different displacement ductility factor for different soil conditions and different seismic fortification intensity is

$$u_m = \mu \frac{1}{R_y} (\frac{T_n}{2\pi})^2 \alpha g \tag{2.6}$$

$$\mu = \begin{cases} 1 + \dfrac{(R_y - 1)T_g}{T_n} & T_n < T_g \\ R_y & T_n \geq T_g \end{cases} \tag{2.7}$$

Where u_m is the maximum displacement of the SDOF system, R_y is the strength reduction factor, T_g is the design characteristic of site, T_n is the natural vibration period of the SDOF system, g is acceleration of gravity.

For $u_m = u_{sd}$, $\mu = \mu_f$, the natural vibration T_e of the equivalent SDOF system is estimated from Figure 1, the effective stiffness at maximum response displacement of the equivalent SDOF system is

$$k_e = \frac{4\pi^2}{T_e^2} m_e \tag{2.8}$$

The yield displacement of the equivalent SDOF system is

$$u_{sy} = u_{sd} / \mu_f \tag{2.9}$$

The base shear under very rare earthquake is

$$V_d = k_e u_{sy} \tag{2.10}$$

Step 4: vertically distributed of the base shear
The base shear is vertically distributed in proportion to the vertical mass and target displacement profiles. Thus

$$F_i = V_d (m_i \mathrm{u}_i) / \sum_{i=1}^{n} (m_i u_i) \tag{2.11}$$

Where F_i is ith floor level earthquake force。

Step: 5 based on analysis of internal forces under earthquake force and vertical load and internal force combination, then structural seismic design is finished according with the Code for Seismic Design of Buildings of China.

3. SEISMIC DESIGN EXAMPLE

A reinforced concrete frame with two bays and six stories, the 1th,2th storey column section size is 500mm×500mm,the 3th,4th storey column section size is 450mm×450mm, the 5th, 6th storey column section size is 400mm×400mm, the beam section size of all stories is 250mm×500mm. the 1th story height is 4.2m, the others stories height is 3.6m. the bay of the frame is 6.0m. The seismic fortification intensity is 8, site soil condition and seismic fortification measures is Ⅱ. Materials are normal concrete with design strength 14.3MPa, grade 335 steel in beams and columns, grade 235 stirrup steel in beams and columns.

The target storey displacement ductility factor is selected $\mu_f = 1.5$ .The $\theta_{y,i}$ is obtained from Eqn. 2.1, where $\varepsilon_y = 0.001675$, $l_b = 5500mm$, $h_b = 500mm$.

The equivalent target displacement of the equivalent SDOF structure is obtained from Eqn. 2.4.

$u_{sd} = \sum_{i=1}^{n}(m_i u_i^2)/\sum_{i=1}^{n}(m_i u_i) = 200.65\text{mm}$. The equivalent mass of the equivalent SDOF system is obtained from Eqn.2.5. $m_e = \sum_{i=1}^{n}(m_i u_i)/u_{sd} = 168.9\text{T}$ .The yield displacement of the equivalent SDOF system is obtained from Eqn.2.9. $u_{sy} = u_{sd}/\mu_f = 200.65/1.5 = 133.77mm$.

According to inelastic displacement spectra (Figure 1), the natural vibration of the equivalent SDOF system is estimated $T_e = 1.92s$. The effective stiffness at maximum response displacement of the equivalent SDOF system is obtained from Eqn.2.8 $k_e = 1806.95kN/m$ .The base shear under very rare earthquake is obtained from Eqn.2.10 $V_d = k_e u_{sy} = 241.72kN$

The yield inter-storey displacement, the ultimate inter-storey displacement and design earthquake force is given in Table 1.

Table 1 yield and ultimate inter-storey displacement, design earthquake force

storey	$\Delta u_{y,i}/mm$	$\Delta u_{u,i}/mm$	F_i/kN
1	36.69	58.04	14.9
2	30.40	45.6	26.61
3	30.68	46.02	38.42
4	30.68	46.02	50.24
5	30.95	46.63	62.16
6	30.95	46.63	49.39

The reinforced concrete frame was designed according to Code for Seismic Design of buildings(GB 50011-2001). Inelastic time history analyses were completed using the computer program OpenSees, Six motion records were used in the inelastic time history analyses, their acceleration spectra is shown in Figure 2.

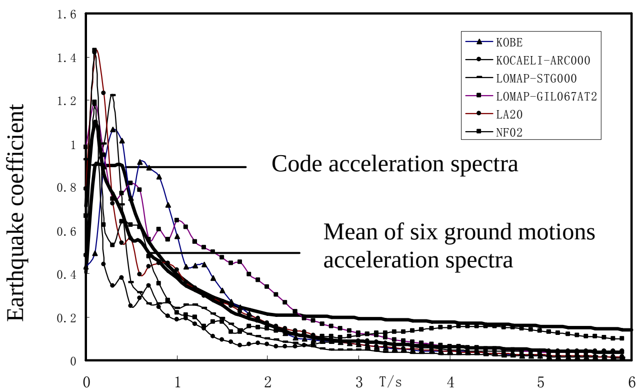
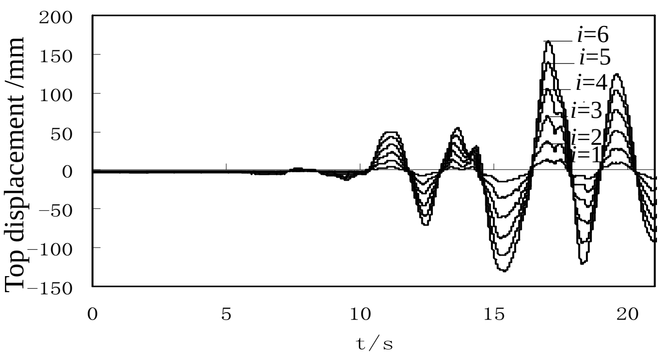


Fig.2 earthquake spectrum used for analysis

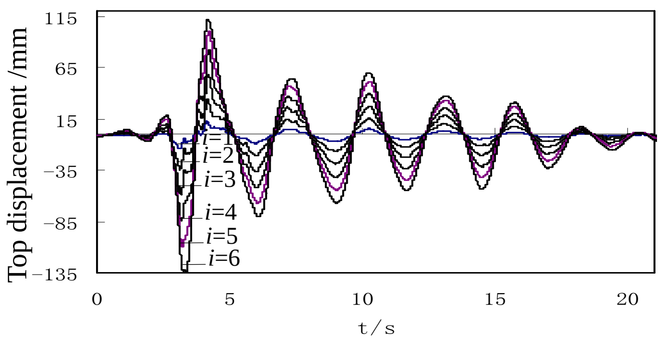
The floor displacements of the frame under the six ground motions were showed in Figure 3.
The inter-storey drifts of the frame under the six ground motions were given in Table 2.
Except the first story displacement response, the others stories displacement response are uniform and displacement ductility factors of each story is range from 1.2 to 1.6, close to the target displacement ductility factor 1.5.

This shows that the use of proper design method, it can make in deformation evenly distributed along the vertical and not to energy-consuming focus on a certain storey for the design of the building under earthquakes.

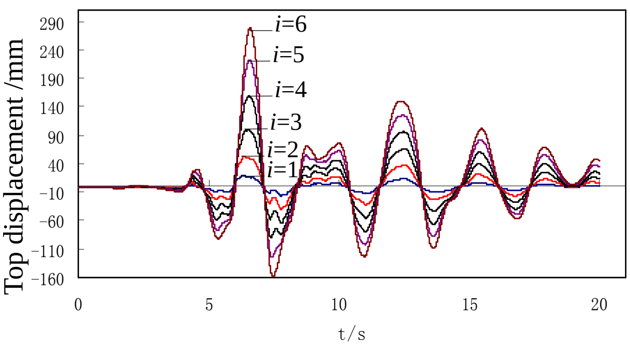
Therefore, the proposed seismic design in the future displacement checking not only the maximum inter-storey drift, as well as checking the margin of each floor displacement, so that it controlled to a certain reasonable limits.



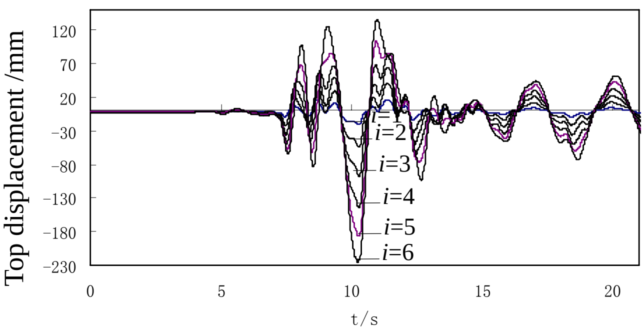
(a) KOCAELI-ARC ground motion



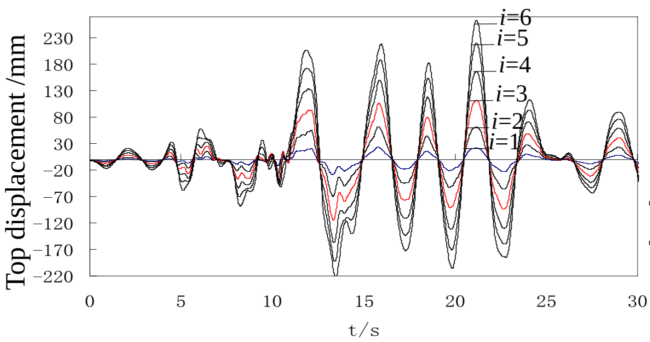
(b) LOMAP-GIL067 ground motion



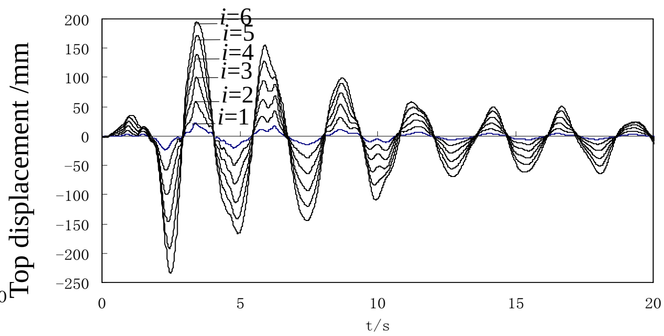
(c) LOMAP-STG ground motion



(d) KOBE ground motion



(e) NF02 ground motion



(f) LA20 ground motion

Figure.3 time history drifts of each floor top

Tab.2 maximum storey drift of six ground motions

Ground motion	Maximum inter-storey drift/mm					
	1	2	3	4	5	6
KOBE	21.2	35.9	47.1	48.9	44.0	46.0
KOCAELI-ARC000	22.4	38.9	43.7	48.3	46.6	37.8
LOMAP-STG000	20.0	36.4	50.7	60.3	61.9	52.3
LOMAP-GIL067AT2	15.2	23.0	29.3	33.5	34.6	32.3
LA 20	24.2	37.9	48.1	53.1	53.1	46.0
NF02	27.5	46.7	51.7	51.5	46.9	39.2
Average inter-storey drift	21.8	36.5	45.1	49.2	47.9	42.3
μ_f	0.56	1.2	1.47	1.6	1.54	1.37

4.CONCLUSIONS

This paper presents the seismic design method to design the building with as far as possible same inter-storey drifts, and in the design does not require iteration. In the building structure under normal load conditions, the ability of the majority of materials are used in the earthquake, so that the whole building in earthquake resistance, rather than concentrated in certain parts.

Based on the results of this paper, the proposed seismic design in the future, displacement checking not only the maximum inter-storey drift, as well as checking the margin of each floor displacement, so that the margin of each floor displacement is controlled to a certain reasonable limits.

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