Study on Amplification Coefficient of Strength Reduction Factor for MDOF Bridge Pier Considering Fixed-based Effect

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Abstract. An analytical method of SRF considering MDOF effect of bridge structure was put forward. The definition and calculation method of amplification coefficient were proposed. Calculation programs were compiled to analyze various equivalent pier MDOF model of bridge through the combination of finite element software. Records from four types of soil sites were selected for nonlinear dynamic time history analysis of fixed-based model. The effect of ductility, period and the type of soil sites on amplification coefficient was is cussed. And a multi-parameter formula was suggested for fixed-based amplification coefficient.

Introduction

As an important part of the Lifeline Project, bridge, plays a crucial role. Some scholars have proposed that non-elastic state through the rational use of elastic seismic force reduction, which is effective to reduce the design seismic force, dissipate seismic energy purposes. Since the 1970s, the strength reduction factor is paid closely attention and studied by scholars. Lots of remarkable results were achieved. At present, most researches of the strength reduction factor for the single degree of freedom system and the building is expanded. But, most of the structure is a multi-degree of freedom system, and is difficult to equivalent to a single degree of freedom system (SDOF). Since the mass distribution of the bridge structure, the stiffness distribution and failure modes are present differences with the building structure. Therefore, multiple degrees of freedom based on the strength of the bridge structure reduction factor needs to study separately.

Proposed Formula of Amplification Coefficient of Strength Reduction Factor

In this paper, the calculation method of strength reduction factor for SDOF is based on the Newmark-β theory. Formula 1 and formula 2 are showed as following:

$$\dot{u}_{i+1} = \dot{u}_i + \left[(1-g)\Delta t\right]\ddot{u}_i + (g\Delta t)\ddot{u}_{i+1} \tag{1}$$

$$u_{i+1} = \dot{u}_i + (\Delta t)\dot{u}_i + \left[(0.5-b)(\Delta t)^2\right]\ddot{u}_i + \left[b(\Delta t)^2\right]\ddot{u}_{i+1} \tag{2}$$

Elastic seismic strength requirements for MDOF can be obtained by modal decomposition method. The motion equation for MDOF excited by earthquake strong motion is listed as following:

$$[M]\{\ddot{m}(t)\} + [C]\{\dot{m}(t)\} + [K]\{m(t)\} = -[M]\{t\}\{\ddot{m}_R(t)\} \tag{3}$$

Where，$[C]$, $[M]$ and $[K]$ is respectively the damping matrix, mass matrix and stiffness matrix of structure. $\{t\}$ is the perturbation vector of structure。

The amplification coefficient C_M of strength reduction factor for MDOF is defined as the ratio of the strength reduction factor of SDOF system to its factor of MDOF system.

$$C_M = R_m / R_{mD} \tag{4}$$

Where, R_m, R_{mD} is respectively the strength reduction factor of SDOF and MDOF.

Because of the bending failure as main form for bridge structure, the suggested reduction factor is defined as the ratio of the bottom moment of pier maintaining perfectly elastic state to its value of

pier while the value of corner ductility is equal to m_i. The calculated equation of R_{mD} and R_m are showed as following.

$$R_{mD} = \frac{M_{MDOF}(m_q = 1)}{M_{MDOF}(m_q = m_i)} \tag{5}$$

$$R_m = \frac{M_{SDOF}(m_q = 1)}{M_{SDOF}(m_q = m_i)} \tag{6}$$

Where, $M_{MDOF}(m_q = 1)$ is the moment of bottom for MDOF maintaining perfectly elastic. $M_{MDOF}(m_q = m_i)$ is the yield moment of bottom for MDOF when corner ductility is equal to m_i. $M_{SDOF}(m_q = 1)$ is the moment of bottom for SDOF maintaining perfectly elastic. $M_{SDOF}(m_q = m_i)$ is the moment of bottom for SDOF when corner ductility is equal to m_i.

Influence of Parameters on Amplification Coefficient

A finite element model (FEM) is established based on SAP2000 structural software. The frame unit, lumped mass on pier top and Link unit is respectively used to simulate the pier body, beam and plastic hinge of bottom pier. Fig.1 shows the FEM for equivalent single pier considering fix-based effect. For analyzing the influence of soil sites on the amplification coefficient of strength reduction factor for MDOF, we selected 10 seismic records in each site, a 40 earthquake strong motions database are created in this paper. Selected earthquake records are listed in Table 1.

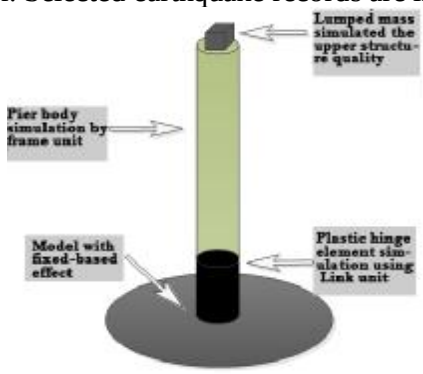


Fig.1 Finite element model of fixed-based

Table 1 Earthquake records selected

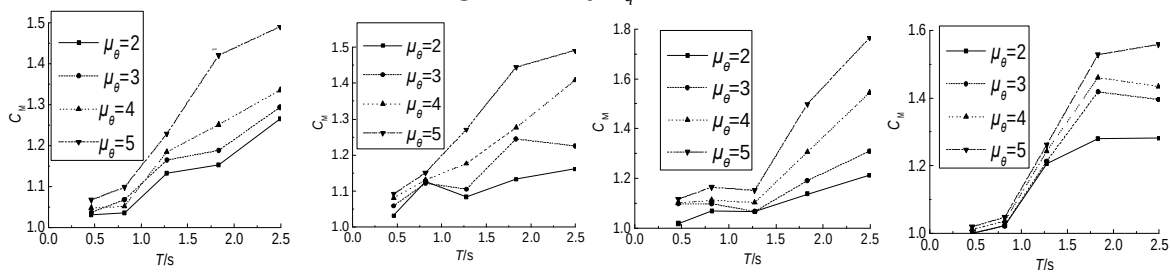
Type of Site	Earthquakes	Records
I	Whittier Narrows, Cape Mendocino Landers ,N. Palm Springs,Northridge San Fernando ,Santa Barbara Victoria, Mexico , Parkfield, Kobe Imperial Valley, Superstitn Hills(B)	P0691,P0806 ,P0885 ,P0856 ,P0514 P0981
II		P0056,P0136,P0266,P0518,P0522 P0808,P0034,P0811
III		P0199 ,P0204,P0207,P0159 ,P0207 P0168,P0724,P0616,P0892,P0893
IV		P0200,P0728 ,P0984,P1041,P1054

Fig.2 shows the calculation results of amplification coefficient in four site types. Some conclusions can be drawn as following.

① The influence of structural vibration period on the spectrum of amplification coefficient C_M is more significant. When determining the level of the target ductility, amplification coefficient significantly increases as the structure period T. The amplification coefficient C_M increases with the target ductility m_q.

② With the structural vibration period T becomes larger, the greater difference between the amplification coefficients under different level of ductility occurs. For I type site, when the value of

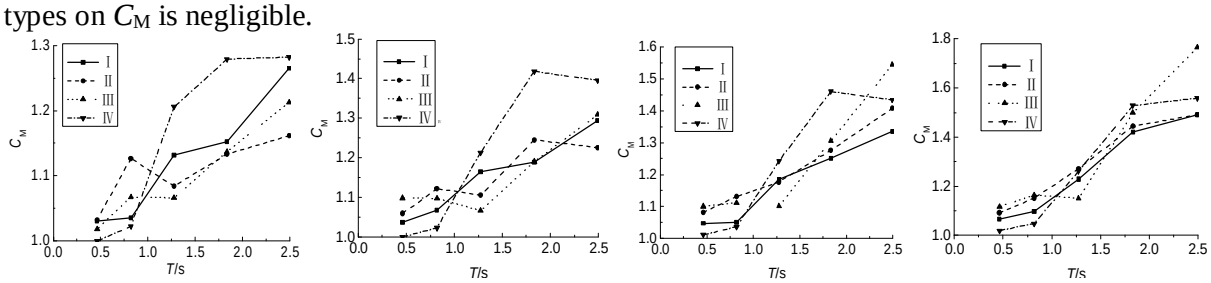
structural vibration period T is equal to 0.46s, the value of C_M when ductility is equal to 5 creases by 23% comparing to its value when ductility is equal to 2, difference between the two is only 0.24. When the value of structural vibration period T is equal to 2.49s, the value of C_M when ductility is equal to 5 creases by 40% comparing to its value when ductility is equal to 2, difference between the two is only 0.42. These results suggest that the structural vibration period T has a significant influence on C_M variation with the target ductility m_q .



(a) Ⅰ type (b) Ⅱ type (c) Ⅲ type (d) Ⅳ type

Fig.2 Mean spectrum of fixed-based C_M of four sites

Fig. 3 shows that the site type has different influence on C_M. When the value of ductility is large, there is small difference for the value of C_M among four sites. But while the value of ductility is small, there is a contrary result. The results showed that the structural vibration period and ductility have a huge influence on C_M increasing with the aforementioned two factors, and effect of site types on C_M is negligible.



(a) m_q =2 (b) m_q =3 (c) m_q =4 (d) m_q =5

Fig.3 Comparison of fixed-based C_M with different m_q

Fitting Formula of Amplification Coefficient for Strength Reduction Factor

Considering the influence of structural deformation ductility (expressed by ductility factor m_q) and structural vibration period T, a suggested relationship of C_M is proposed and used to fit the parameters by use of Least squares method based the calculation spectrum of C_M and large number of calculations. The formula of C_M is as follows.

$$C_M = \frac{A_1 - A_2}{1 + \left(\frac{T}{1.75}\right)^p} + A_2 \tag{7}$$

Where, A_1, A_2 and P is a function of the size of corner ductile m_q . Regression coefficient as follows:

$$A_1 = 0.03193 m_\theta + 0.93065 , \quad A_2 = 0.01792 m_\theta^{\ 2} + 1.26974 , \quad P = 0.69116 m_\theta + 0.55796$$

Fig. 4 shows the results of the fitting function comparing with calculation result. We can see the effect of a good functional fit.

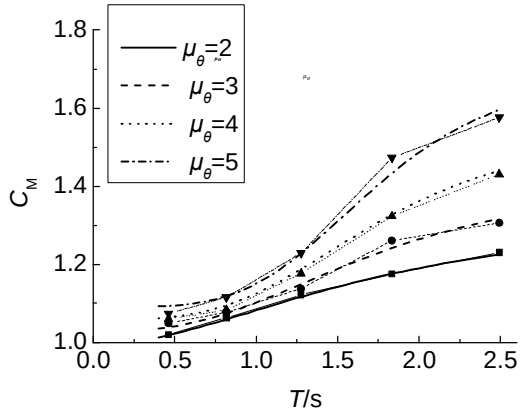


Fig.4 Comparison between fitting spectrum and average spectrum of CM

Conclusions

The calculation model of equivalent single pier is created based on the typical bridge in paper. We did a lot of quantitative analysis for influence of structural vibration period, ductility level and site type on the amplification coefficient of strength reduction factor of bridge considering fixed-based effect. The results showed that the structural vibration period and ductility have a huge influence on the amplification coefficient C_M increasing with the aforementioned two factors, and effect of site types on the amplification coefficient C_M is negligible. And then, we proposed the formula of strength reduction factor for MDOF bridge pier considering fixed-based effect, and given the reasonable values of the correlation coefficient with the regression analysis.

Acknowledgements

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