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Research Article

The Damage Analysis of Usu Bridge under Seismic Load

[1]Jian-Hui Gao and [2]Li Zhang
[1]The Construction Headquarters of Usu Bridge in Heixiazi Island, Harbin, P.R. China
[2]Department of Astronautic Science and Mechanics, Harbin Institute of Technology, P.R. China

Abstract: In order to obtain the dynamic response of Usu bridge the compression damage model of concrete materials and the finite element method are used in this study. The frequency and the main vibration mode of Usu bridge are calculated. The damage distribution and the location of maximum damage of concrete structures under the four kinds of seismic load are obtained. The results show that the maximum damage of bridge deck occurs in close to support position, the maximum compression damage of the main tower occurs in the upper tower root place. Therefore, in the construction and maintenance process note the influence of seismic load of in these positions.

Keywords: Concrete damage, finite element analysis, seismic load, Usu bridge

INTRODUCTION

The cable-stayed bridge is a cable supported structure system which consists of three basic components tower, beams and cables, generally performs flexible force characteristics. The cable-stayed bridge structure can across larger valleys, rivers and other obstacles with the support of many oblique cables of the bridge tower. The design and construction technology of cable-stayed bridge in China has been in the advanced status. For example, the world famous Shanghai Yangpu Bridge, is a composite beam cable-stayed bridge with a span of 602 m. After a series of crossing passages have been included in the agenda, China has built cable-stayed bridges that have spans above 1km, such as the Sutong Bridge with a span of 1088 m and the Stonecutters Bridge with a span of 1018 m (Chen, 2008, 2006).

Damage mechanics is the study of materials and structure deformation and failure of one of the important theory. Under load and environmental comprehensive function engineering material failure happened, when reaching the critical point material. But in the fracture occurred before, the material will undergo a gradual damage degradation process, in this process, the material is not complete failure, but there are some degree of damage. Macro performance for stiffness, strength of the drop, the micro is produced distribution of dislocation, micro void, micro crack and so on the different degree of damage. For concrete material, mainly due to the stress function damage, the damage appeared material and no obvious irreversible deformation. Describe the concrete damage model mainly includes: Mazars damage model, Loland damage model, Sidoroff damage model, index function damage mode (Xu, 2004). The concrete plastic damage model using isotropic elastic damage with isotropic tensile and compression plasticity theory to represent concrete inelastic behavior, can simulate low confining pressure, concrete is drab, cycle or dynamic load under the action of mechanical behavior. Some scholars on concrete plastic damage model are studied. Lee and Fenves (1998) established damage plastic continuous constitutive for concrete dam seismic response analysis. Based on the effective stress and the plastic strain (Peter and Milan, 2006) established for concrete failure three shaft damage plastic constitutive. Ludovic *et al*. (2006) based on isotropic damage and compressive yield plastic surface established damage elasto-plastic constitutive. The plastic damage constitutive model of Lee was studied based on ABAQUS software, such as Zhang *et al*. (2010), Wang *et al*. (2012) and Fang and Zhang (2007). In the seismic load under the action of dynamic response analysis of the bridge structure is more, but less damage analysis.

The span of the main bridge of Usu Bridge is (140+140 m), symmetrical set to the main tower, the cross-section of the bridge deck with large pick wall combined by steel and box is adopted, the anchor point of cable-stayed beam is anchorage in steel box by steel anchor box. The background of this paper is the construction of Usu Bridge, for the concrete structures in Usu Bridge, the damage is calculated and the evolution of the injury is also known so that it is convenient to direct the construction and to maintain the bridge.

Corresponding Author: Li Zhang, Department of Astronautic Science and Mechanics, Harbin Institute of Technology, P.R. China

Table 1: The elastic properties of the concrete

Material	Density (kg/m^3)	Elastic modulus (GPa)	Poisson's ratio	Coefficient of thermal expansion
C50	2600	34.5	0.167	1*10-5
C55	2600	35.5	0.167	1*10-5

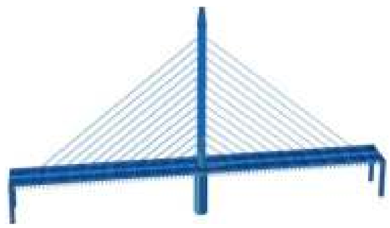

Fig. 1: The geometric model of the main bridge of Usu Bridge

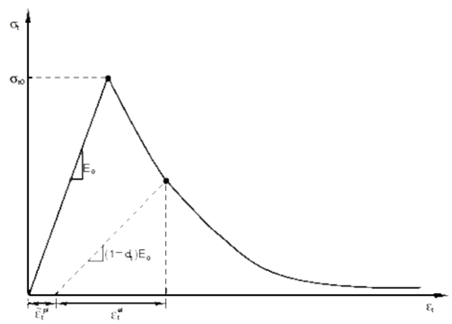

Fig. 2: The damage description of uniaxia l tension

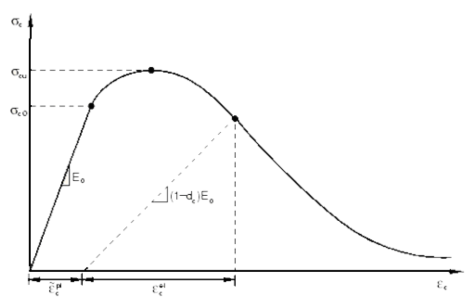

Fig. 3: The damage description of uniaxial compression

FINITE ELEMENT MODELING

Geometric model: Shell elements are used in the modeling of the upper and lower parts of the main tower, concrete columns with variable cross-section are constructed and the horizontal and vertical reinforcements are paved on the surface. The main beam of Usu Bridge is of full-closed box girder cross-section, the free torsion stiffness play a decisive role while the constrained torsional stiffness is relatively weak, thus selecting the “fishbone” model, using beam elements, creating the corresponding box-shaped and H-shaped cross section according to the sectional shape of the stringers and beams. The shell elements are used in bridge deck, staying out of the location for the Unicom Department of the tower, the thickness of the bridge deck is 0.25 m. Truss elements are used in lasso. For the force at spire is less, mainly play a decorative role, thus the simplification is larger and solid elements

Table 2: The plastic parameters of compression damage for concrete

Stress (MPa)			
C50	C55	Inelastic strain	Damage
17.4	18.5	0	0
18.7	19.9	0.0004	0.1299
22.0	23.4	0.0008	0.2429
23.5	25.0	0.0013	0.3412
10.8	11.5	0.005	0.8243
2.1	2.3	0.01	0.9691

Table 3: The material properties of steel

	Elastic modulus (Gpa)	Yield stress (Mpa)	Strength limit (Mpa)	Elong ation (%)
S235	200	235	370	25
S335	200	335	455	17
Cable-stayed	205	370	510	20
Main structure	206	1490	1670	4

are used here. The supports are solid elements. The geometric model of the full-bridge is as shown in Fig. 1.

Material properties: The concrete materials mainly used in Usu Bridge are C50, C55, whose elastic properties are shown as in Table 1.

In this study, the uniaxial tension and compression damage model is used for the damage model of concrete, as for uniaxial tensile test and uniaxial compression test, we establish tensile curve and compression curve separately, as shown in Fig. 2 and 3. A number of unloading modulus are also established the damage is calculated by the reduction ratio that uninstall elastic modulus with respect to the initial elastic modulus:

Uniaxial tension $E = (1 - d_t)E_0$

Uniaxial compression $E = (1 - d_c)E_0$ (1)

The compression damage plastic parameters of concrete materials C 50 and C 55 are got according to the experimental data of the literature (Li, 2010) and the material properties of C 50 and C 55 (Table 2).

The properties of the steel used in Usu Bridge are as shown in Table 3. Poisson's ratio takes for 0.3. Bilinear models are used in plastic nature:

$$E_1 = \frac{\sigma_1}{\varepsilon_1} \quad E_2 = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \tag{2}$$

where,

Table 4: The seismic load type

Load type	Type 1		Typ2	
	$a1$	$a2$	$a1$	$a2$
E1	0.033 g	0.022 g	0.033 g	0.022 g
E2	0.101 g	0.067g	0.101 g	0.067 g

E_1 = The Young's modulus of elastic stage
E_2 = The Young's modulus of plastic stage
σ_1 = The yield stress
σ_2 = The elastic limit
ε_1 = The yield strain
ε_2 = The elongation

The boundary conditions and the load: Four bearings and the bottom of the lower part of the main tower are fixed-side prixed-side processing.

According to the geographical location of Usu bridge, total four load programs are considered for the dynamic analysis: such as shown in Table 4.

Where, Type1- In the plane along the bridge to the applied seismic load; Type2- In the plane cross the bridge to the applied seismic load; a_1-Level to acceleration peak; a_2-Plumb acceleration peak.

RESULTS AND ANALYSIS

First ten order vibration mode and frequency are calculated, Fig. 4 for the first order main vibration mode and Table 5 for the first ten order frequency. The compression damage under various load types can be calculated. The compression damage distribution of the concrete bridge deck and the main tower under type 1 of E1 load are shown as Fig. 5 and 6. The compression damage distribution of the concrete bridge deck and the main tower under type 2 of E1 load are shown as Fig. 7 and 8.

The compression damage distribution of the concrete bridge deck and the main tower under type 2 of E2 load are shown as Fig. 9 and 10.

Table 5: The first ten order frequency

Order	Frequency (Hz)
1	0.18
2	0.48
3	0.95
4	1.06
5	1.14
6	1.30
7	1.31
8	1.45
9	1.47
10	1.71

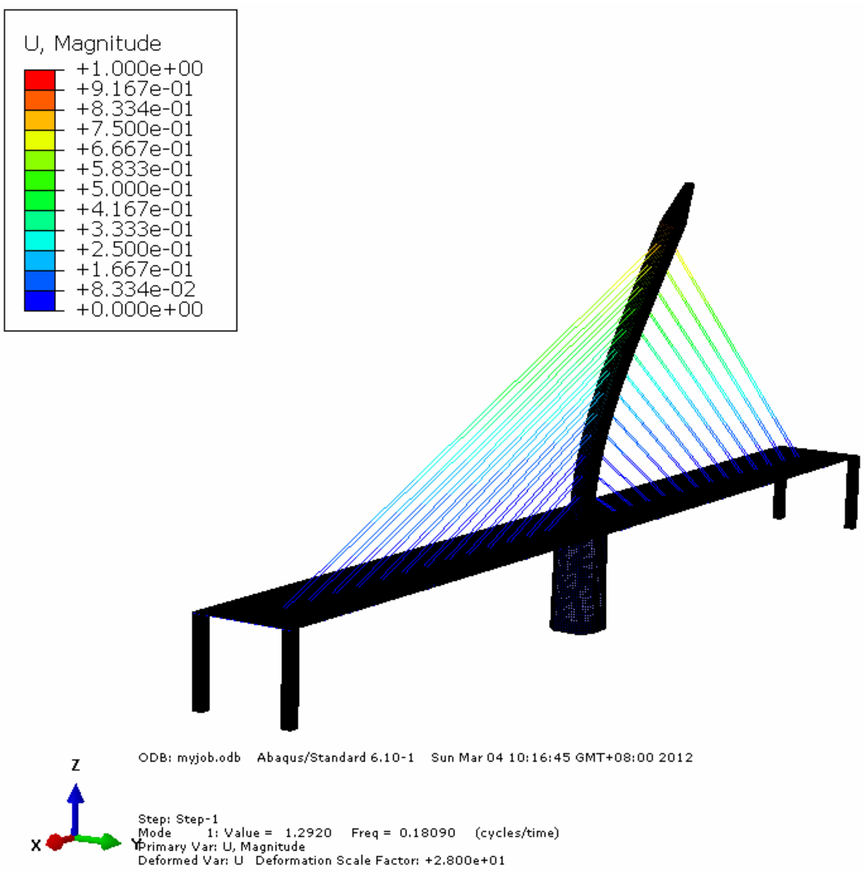

Fig. 4: The first order main vibration mode

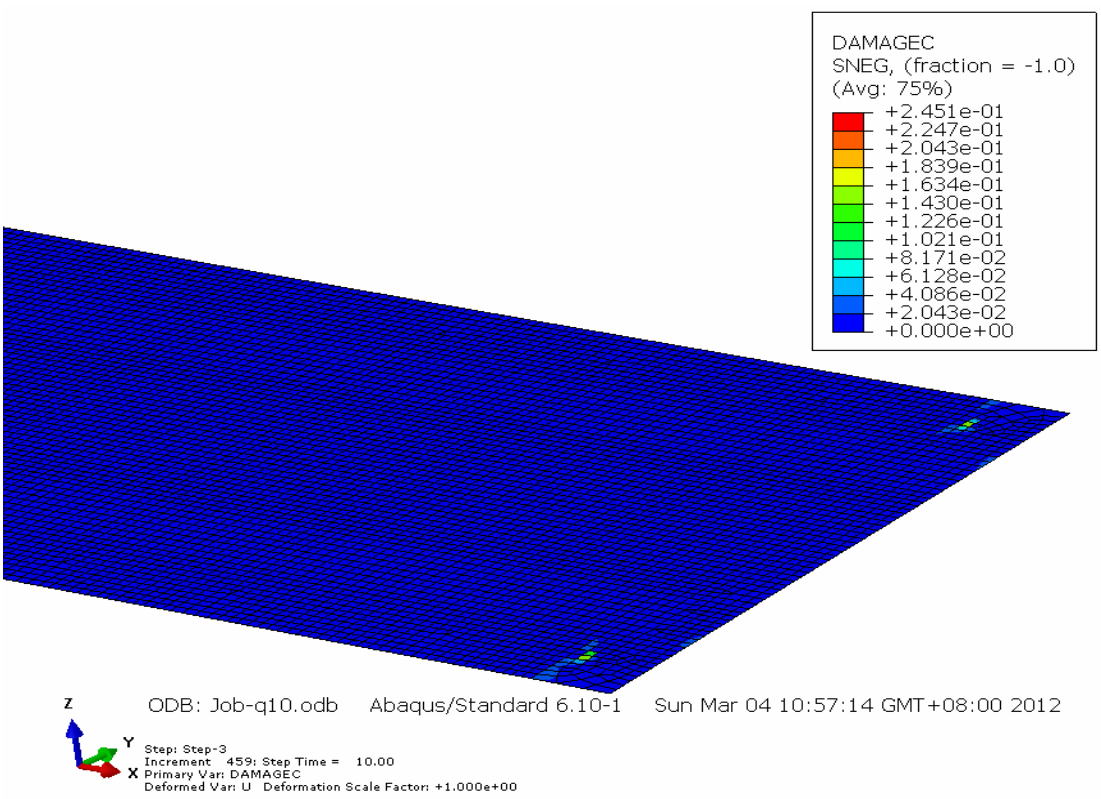

Fig. 5: The compression damage of the bridge deck under type 1 of E1 load

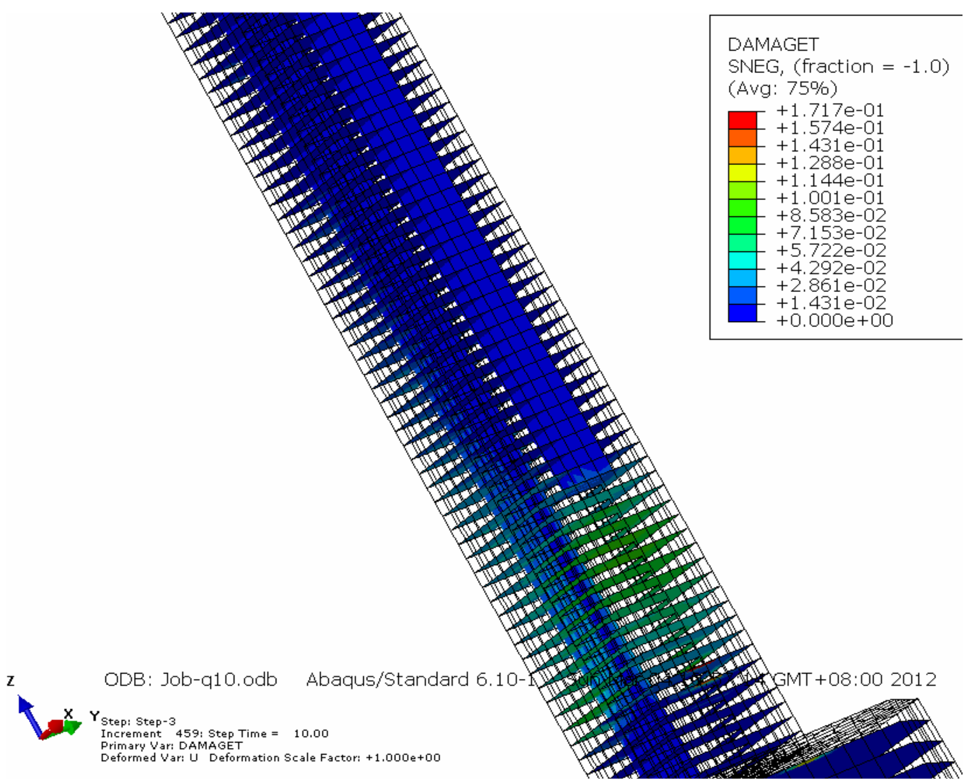

Fig. 6: The compression damage of the main tower under type 1 of E1 load

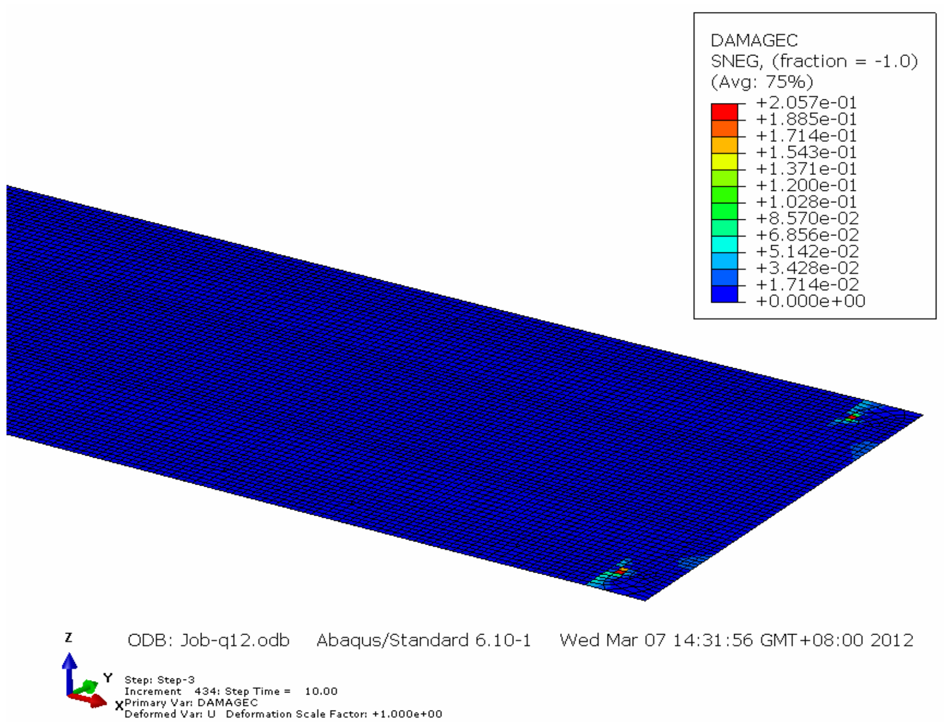

Fig. 7: The compression damage of the bridge deck under type 2 of E1 load

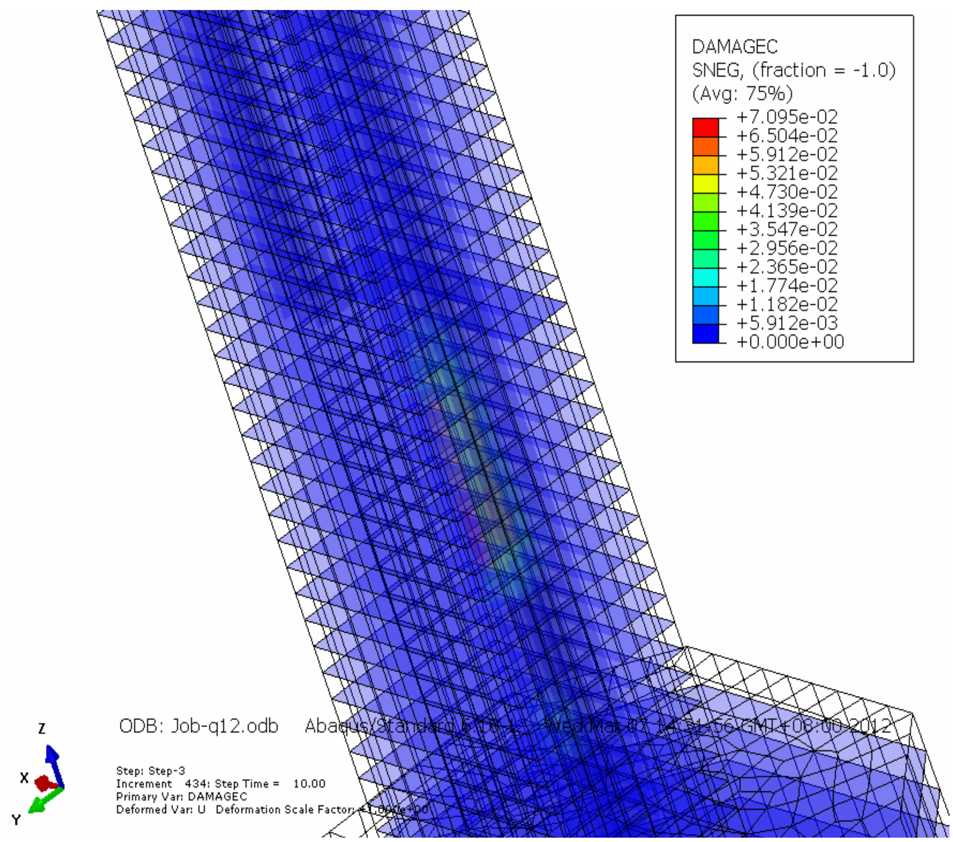

Fig. 8: The compression damage of the main tower under type 2 of E1 load

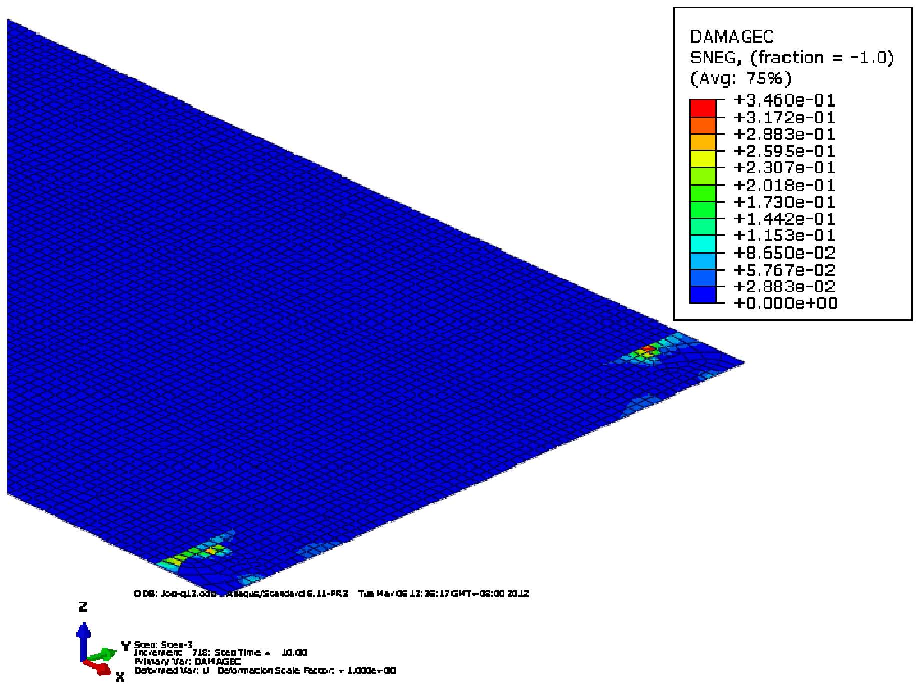

Fig. 9: The compression damage of the bridge deck under type 1 of E2 load

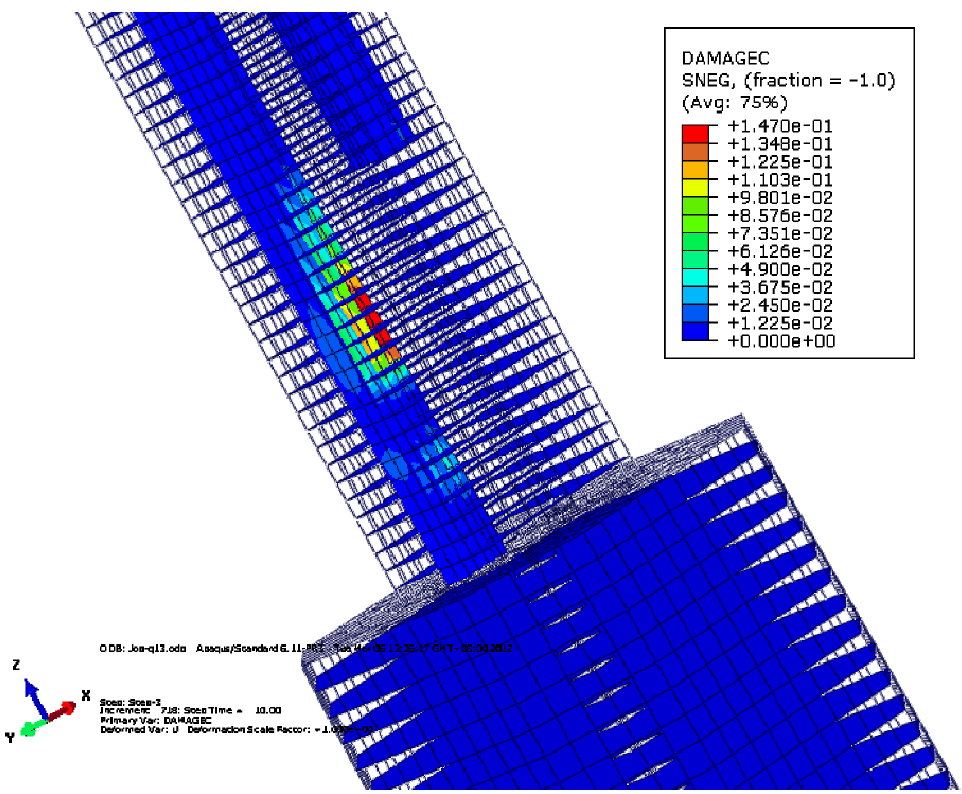

Fig. 10: The compression damage of the main tower under type 1 of E2 load

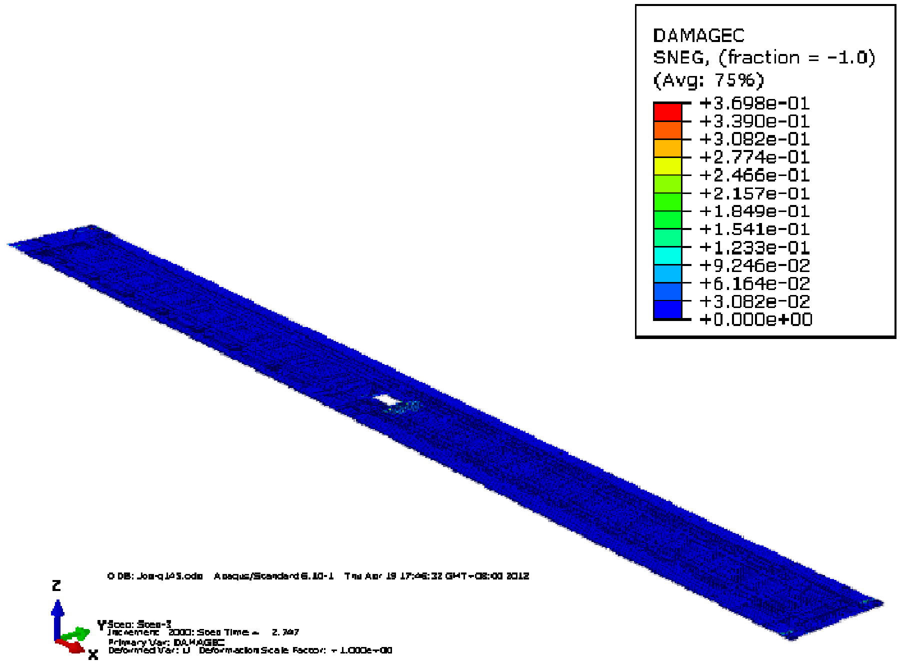

Fig. 11: The compression damage of the bridge deck under type 2 of E2 load

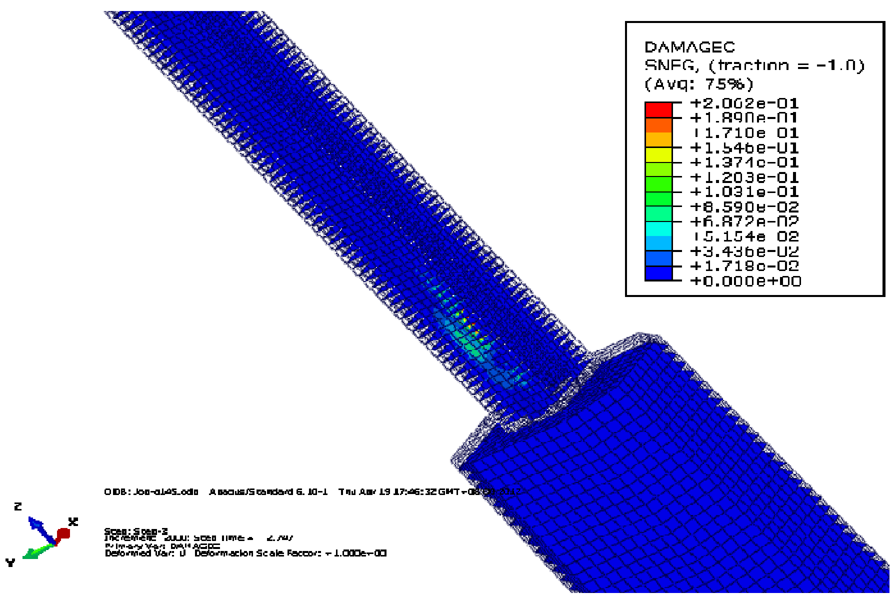

Fig. 12: The compression damage of the main tower under type 2 of E2 load

Table 6: The maximum compression damage of the concrete bridge deck and the main tower

Loading type	Type 1 of E1	Type 2 of E1	Type 1 of E2	Type 2 of E2
Bridge deck	0.2451	0.2057	0.3460	0.3698
Main tower	0.1717	0.0710	0.1470	0.2062

The compression damage distribution of the concrete bridge deck and the main tower under type 2 of E2 load are shown as Fig. 11 and 12.

The maximum compression damage of the concrete bridge deck and the main tower under various load types are shown in Table 6.

Observation Table 6 and Fig. 5 to 12 shows that for bridge deck is concerned, the largest compression damage happen to close to the edge block position and damage along the cross bridge to the forward expand, E1 load effect, the bridge to the load compression damage is bigger and in E2 load, cross the bridge to load compression damage bigger; For the main tower, the biggest compression damage occurs in the main tower top roots and E1 load under the action of the bridge, to load the largest compression damage is bigger and in E2 load, cross the bridge to load leads to greater compression damage.

CONCLUSION

- Calculation for the first ten order frequency and the main vibration mode.
- Calculated under seismic load in concrete structure damage distribution, determination of the maximum damage value and position.
- In the construction and maintenance process note seismic load on bridge deck and the main tower effects of damage.

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REFERENCES

Chen, M.X., 2006. Development and outlook of cable-stayed bridge. J. China Foreign Highway, 26(4): 76-86.

Chen, G.H., 2008. The development situation and development trend of the cable-stayed bridge. Shanxi Architecture, 34(19): 320-321.

Fang, Q.H. and Y.D. Zhang, 2007. Investigation into static properties of damaged plasticity model for concrete in ABAQUS. J. PLA Univ. Sci. Technol., 8(3): 254-260.

Li, X.M., 2010. The damage evolution of concrete pavement under impact loading. MA Thesis, Harbin Institute of Technology.

Lee, J. and G.L. Fenves, 1998. A Plastic-damage concrete model for earthquake analysis of dams. Earthq. Eng. Struct. Dyn., 27(9): 937-956.

Ludovic, J., H. Antoio and P.C. Gilled, 2006. An Elastic plastic damage formulation for concrete: Application to elementary tests and comparison with an isotropic damage model. Comput. Method. Appl. M., 195(52): 7077-7092.

Peter, G. and J. Milan, 2006. Damage-plastic model for concrete failure. Int. J. Solids Struct., 43(22-23): 7166-7196.

Wang, W., L.L. He, T.T. Li and X. Huang, 2012. Seismic response of bridge Pier based on plastic-damage model for concrete. J. Yangtze River Scientific Res. Institute, 29(6): 79-86.

Xu, J.X., 2004. The damage mechanics analysis of concrete structure. Ph.D. Thesis, Hehai University.

Zhang, J., Z.X. Zhong and C.Y. Chen, 2010. Yield criterion in plastic-damage models for concrete. Acta Mechanica Solida Sinica, 23(3): 220-230.