Study on Collapse-mechanism of Long Span and High-pier Continuous Rigid Frame Bridges during Strong Earthquake

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ABSTRACT :

In this paper, dynamic response of long span and high-pier continuous rigid frame bridges (70m+127m+70m) during strong earthquake is studied with damage model of reinforced concrete by the explicit dynamic analysis code. The development of the concrete elements from cracking to failure and the bridge from part collapse to the whole collapse of the bridge are studied. The damage and collapse mechanisms during strong earthquake are given of Long Span and High-pier Continuous Rigid Frame Bridges. References are provided for seismic analysis of this kind of bridges.

KEYWORDS: Continuous Rigid Frame Bridges; strong earthquake; Collapse-mechanism; analysis of explicit dynamic

1. FOREWORD

With the economy developed at top speed in China, the development of the highway in mountainous areas is fast, so that more and more Long Span and High-pier Continuous Rigid Frame Bridges were built. Much attention is paid to the bridges built in seismic regions because earthquake happens frequently in China. For example, the nearby structures and bridges were destroyed by the 8 M. Wenchuan earthquake in may 2008. In order to study the mechanism of damage and failure and modes of collapse of the Long Span and High-pier Continuous Rigid Frame Bridges, take the Huachun bridge in Baise City Guangxi for an instance in this paper. It is importantly concluded that the method and the conclusion can be used to the same bridges.

2. GENERAL SITUATION AND THE FINITE ELEMNT MODEL

The Huachun bridge in Baise is three-span (70 m +125m+70m) prestressed concrete rigid frame bridge. The material of box girder is C50 and the pier is C30. The height of bridge pier is 70m. The side spans connect with 5# pier and 8# abutment. The elevation drawing is shown in the Figure 1.

On the basis of design drawings of the bridge, using general finite element code to build the three-dimensional space model of the bridge. The whole model is made by ispoparametric element of solid, as shown in Figure 2. The direction of along the bridge as the X-axis, the cross-bridge as the Y-axis and vertical direction as the Z-axis of the model. Boundary condition: fixed constraint is applied to the bottom of the bridge pier; horizontal and lateral restrained is applied to the buttress at abutment span of the bridge.

Hypotheses of the model
(1) The material of the girder and bridge pier is a integrated model.
(2) The perstress of girder is equal the stress of gravitation and Construction.
(3) Damping coefficient of the materials equal 0.05.

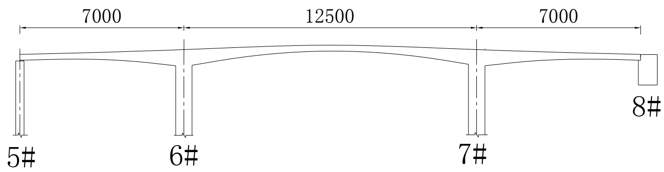


Figure 1 The elevation drawing of the bridge(cm)

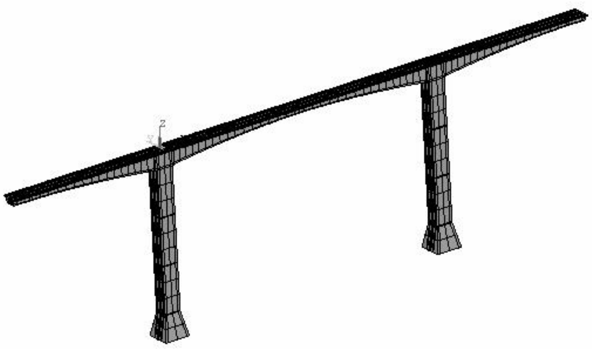


Figure 2 The finite element model

3. MATERIAL DEFINITION

The concrete model was primarily developed to simulate the deformation and failure of concrete in the structure of bridge. The concrete model is commonly referred to as a smooth or continuous surface cap model. A smooth and continuous intersection is formulated between the failure surface and hardening cap, as shown in Figure 2.

(1) The Main Features of the Model

Isotropic constitutive equations.
Three stress invariant yield surface with translation for prepeak hardening.
A hardening cap that expands and contracts.
Damage-based softening with erosion and modulus reduction.
Rate effects for increasing strength in high-strain rate applications.

This is a cap model with a smooth intersection between the shear yield surface and hardening cap, as shown in Figure 3.

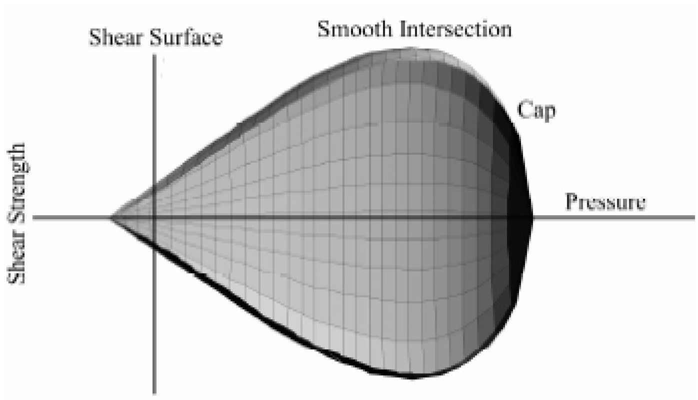


Figure 3 General shape of the concrete model yield surface in two-dimensions

(2) Stress Invariants

The yield surface is formulated in terms of three stress invariants. as follows:

$$J_1 = 3P$$
$$J_1' = \frac{1}{2} S_{ij} S_{ij}$$
$$J_3' = \frac{1}{3} S_{ij} S_{jk} S_{ki} \qquad (1)$$

(3) Plasticity Surface

The three invariant yield function is based on these three invariants, and the cap hardening parameter, as follows:

$$f(J_1, J_2', J_3', \kappa) = J_2' - \Re^2 F_f^2 F_c \qquad (2)$$

(4) Shear Failure Surface

$$F_f(J_1) = \alpha - \lambda \exp^{-\beta J_1} + \theta J_1 \qquad (3)$$

(5) Rubin Scaling Function

$$Q_1 = \alpha_1 - \lambda_1 \exp^{-\beta_1 J_1} + \theta_1 J_1 \qquad (4)$$
$$Q_2 = \alpha_2 - \lambda_2 \exp^{-\beta_2 J_1} + \theta_2 J_1 \qquad (5)$$

(6) Cap Hardening Surface

$$F_c(J_1, \kappa) = 1 - \frac{[J_1 - L(\kappa)][|J_1 - L(\kappa)| + J_1 - L(\kappa)]}{2[X(\kappa) - L(\kappa)]^2} \qquad (6)$$

Where $L(\kappa)$ is defined as:

$$L(\kappa) = \begin{cases} \kappa & if \quad k > k_0 \\ k_0 & otherwise \end{cases}$$

The intersection of the cap with the J_1 axis is at $J_1 = X(\kappa)$. This intersection depends upon the cap ellipticity ratio *R*, where *R* is the ratio of its major to minor axes:

$$X(\kappa) = L(\kappa) + RF_f(L(\kappa)) \qquad (7)$$

The cap moves to simulate plastic volume change. The motion (expansion and contraction) of the cap is based upon the hardening rule:

$$\varepsilon_v^p = W(1 - \exp^{-D_1(x-x_0) - D_2(x-x_0)^2}) \qquad (8)$$

(7) Shear Hardening Surface

In unconfined compression, the stress-strain behavior of concrete exhibits nonlinearity and dilation prior to the peak. Such behavior is be modeled with an initial shear yield surface, $N_H F_f$, which hardens until it coincides with the ultimate shear yield surface.

(8) Damage

Concrete exhibits softening in the tensile and low to moderate compressive regimes.

$$\sigma_{ij}^{d} = (1-d)\sigma_{ij}^{vp} \tag{9}$$

(9) Ductile Damage

$$\tau_c = \sqrt{\frac{1}{2}\sigma_{ij}\varepsilon_{ij}} \tag{10}$$

(10) Softening Function

Ductile Damage

$$d(\tau_c) = \frac{d_{\max}}{B}\left[\frac{1+B}{1+B\exp^{-A(\tau_c-\tau_{0c})}}-1\right] \tag{11}$$

The smooth or continuous surface cap model is implemented the model into a beta 971 version of LS-DYNA as material model 159 by LSTC.

The card of material model 159 is defined as shown Table 1. And it isn't list in this paper of the pier material.

Table 1 Data for box beam of bridge

*MAT_CSCM_TITLE							
MID	RO	NPLOT	INCRE	IRATE	ERODE	RECOV	IRETRC
C50	2550	1	0	1	1.1	1	0
PreD							
0							
G	K	α	θ	λ	β	NH	CH
1.8e10	2.1e10	15.16	0.3143	10.51	0.01929		
α_1	θ_1	λ_1	β_1	α_2	θ_2	λ_2	β_2
0.7473	1.2e-3	0.17	0.0646	0.66	1.2e-3	0.16	0.065
R	X_0	W	D_1	D_2			
5	93.31	0.05	2.50E-4	3.49E-7			
B	G_{fc}	D	G_{fs}	G_{ft}	pwrc	pwrt	pmod
100	11.0e3	0.1	106.0	106.0	5	1	0
$\eta 0 \chi$	N_c	$\eta_{0\tau}$	N_t	overc	overt	Srate	repow
1.13E-4	0.78	6.71E-5	0.48	3.25e7	6.2e6	1	1

4. EXPLICIT ANALYSIS ON THE BRIDGE DURING STRONG EARTHQUAKE MOTIONS

In this paper, the analysis was performed by the ground motion of EL-Centro earthquake record, as shown in Figure 4. In order to study the damage mechanism and collapse mode of the bridge, the seismic wave hadn't been adjusted. The method of uniform excitation was used to analyses, from X-axis and Y-axis.

In this paper, central difference method is adopted to solve the dynamic equation by LS-DYNA finite element code beta version 971.

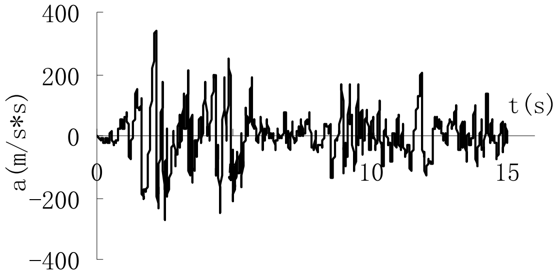
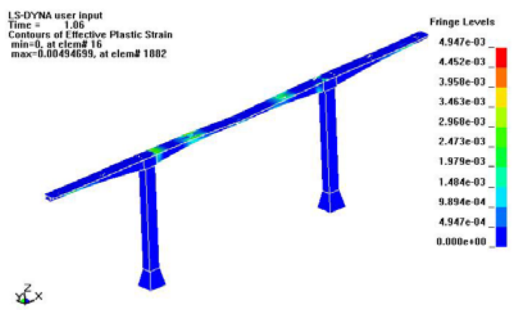


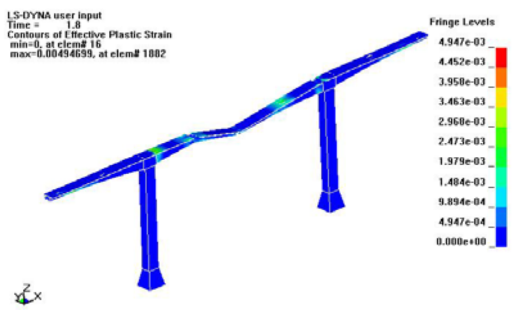
Figure 4 EL-Centro Wave

5. RESULT ANALYSES

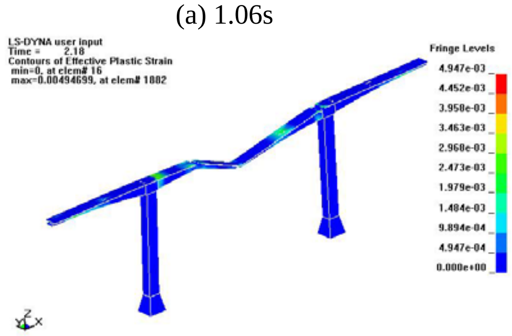
The collapse Process of the bridge is simulated by LS-DYNA971 during the strong earthquake. The result shows: In the range from the beginning to 1.06s, the structure is in elastic stage, at 1.06s, the bridge has entered the plastic stage. And with the development of plastic deformation, firstly, some elements have damaged and failure at closure segment of midspan, and plastic hinges appeared at the places of quarters of midspan, as shown in Figure 5(a). Then fracture appeared at the sections of closure segment of midspan, some elements of quarter damaged and failed, plastic hinges appeared at the cantilevers 6# and 7# piers at 1.80s, as shown in Figure 5(b). At 2.18s, the cantilever of 7# pier appeared fracture and the plastic strain increased at closure segment of side spans, as shown in Figure 5(c). And cantilever of side span of the bridge appeared damaged and failed at 2.52s, as shown in Figure 5(d). The closure segment of side span damaged and failed at 3.34s, as shown in Figure 5(e). With damaged and failure development, variable Cross-Section of 6# pier appeared fracture and the whole bridge became unstable and collapsed until 4.56s, as shown in Figure 5(f).



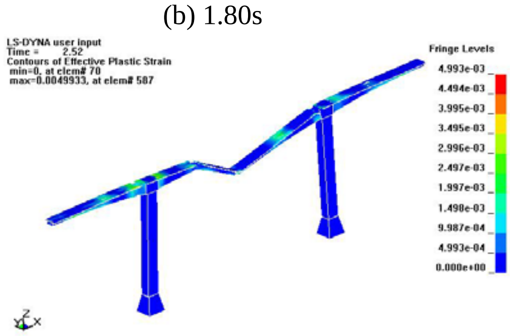
(a) 1.06s



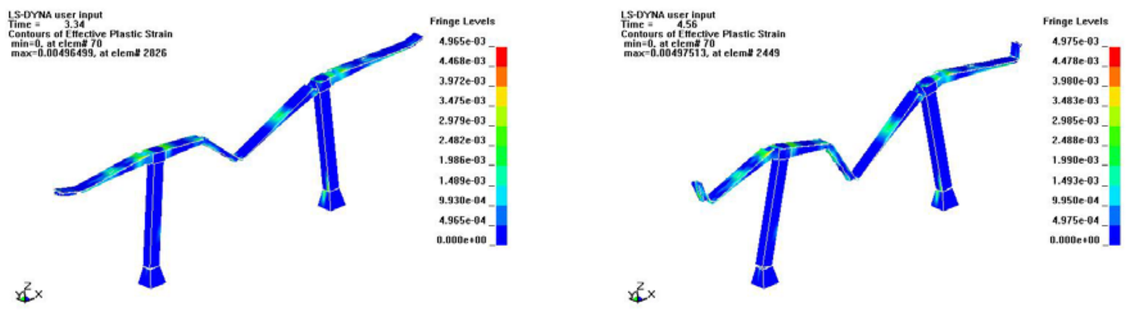
(b) 1.80s



(c) 2.18s



(d) 2.52s



(e) 3.34s (f) 4.56s

Figure 5 The simulation of the damaged mechanism and collapse mode of the bridge during strong earthquake motion

6. SUMMARY AND SUGGESTION

Some conclusions have been drawn by study on damage mechanism and collapse mode of three span and high-pier continuous rigid frame bridges (70m+127m+70m) during strong earthquake motion.
(1) The concrete model of smooth or continuous surface cap model is effective to analyses the damage and collapse of concrete bridge.
(2) During strong earthquake motions, the closure segment of midspan appeared damage and failed firstly. The plastic hinges appeared at the quarter and cantilever section of midspan.
(3) The sections of cantilever and closure segments of side spans are weak under strong earthquake motions.
(4) The collapse of the bridge occurs until the closure segments, cantilevers and piers fracture.
(5) The material nonlinear should be considered for seismic design, and the variable Cross-Section of piers should be seismic checked.

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