



## Pushover Analysis of Reinforced Concrete Bridges under Chloride-Induced Corrosion

M. R. Seify Asghshahr, A. R. Rahai\*

Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran

**ABSTRACT:** Long-term seismic performance determination of reinforced concrete bridges is one of the effective factors in service life estimation of these structures. Chloride induced corrosion results in deterioration of critical members in the service life of reinforced concrete bridges and therefore leads to degradation of long-term seismic performance of the bridge. Due to seismicity and high rate of corrosion in reinforced concrete structures due to the corrosive environmental condition in Persian Gulf region, evaluation of corrosion-induced degradation on the long-term seismic performance of existing bridges in this region has a high importance. In order to evaluate this problem, at first based on studies done related to Persian Gulf region, corrosion initiation time of columns as critical seismic members of the bridge has been determined. Then effects of corrosion on the reinforced concrete column at specific time intervals (0, 15, 30, 45, 60, 75, 90 years) in bridge service life have been calculated. Effects of corrosion include degradation of cover and core concrete, steel, and bonding between concrete and steel that result in modification of stress-strain relationship of materials. In the next step, at each time interval based on the modified stress-strain relationship of materials, moment-curvature analysis of bridge column conducted and characteristics of plastic hinge have been determined. Finally, based on plastic hinge characteristic at each time interval, pushover analysis of bridge in longitudinal and transverse directions conducted and bridge capacity curves at mentioned time intervals have been compared. Results indicate the time-dependent degradation of bridge capacity under corrosion. According to the obtained results, in order to ensure the long-term seismic performance of reinforced concrete bridges in corrosive environments, value for an increase of design base shear has been proposed.

### Review History:

Received: 1 February 2016  
Revised: 17 August 2016  
Accepted: 24 October 2016  
Available Online: 5 December 2016

### Keywords:

Reinforced Concrete Bridge  
Chloride Corrosion  
Seismic Performance  
Plastic Hinge  
Pushover Analysis

### 1- Introduction

Dominating deterioration mechanism for reinforced concrete bridges in the marine environment is chloride-induced corrosion. Corrosion leads to significant decrease in strength and ductility of reinforced concrete structures [1]. In bridge service life, a gradual decrease of performance happens due to cracking and softening of cover concrete [2], strength degradation of core concrete [3], sectional area loss of steel and degradation of its mechanical properties [4] and bonding loss between concrete and steel [5]. Long-term performance in bridge service life is a significant parameter for maintenance, rehabilitation and repair of these structures. One of the effective factors in an estimation of reinforced concrete bridge service life in seismic regions is a determination of the long-term seismic performance of structures. Chloride-induced corrosion in RC bridge results in deterioration of the bridge critical members and therefore the long-term seismic performance of bridge.

In the past years, evaluation of corroded bridge seismic performance has been conducted with various aspects. Time-dependent reliability of RC bridges with different structural systems under long-term chloride diffusion has

been investigated. In order to evaluate the general effects of corrosion on the reinforced concrete components and bridge overall system response and also an initial design of bridges, different approaches have been proposed. A common effect of cumulative seismic damage and corrosion deterioration of bridge has been evaluated. In order to investigate of corrosion effect on the seismic response of bridge, fragility curve of the bridge at different time intervals in bridge service life has been developed. General procedures for nonlinear analysis of corroded RC bridges have been presented [6-8].

Persian Gulf region due to an elevated temperature, strong drying winds, large fluctuation of temperature and high chloride concentration is one of the most corrosive environments in the world. Due to the high rate of corrosion and seismicity of this region, evaluation of the long-term seismic performance of existing bridges in this region under corrosion state has a significant importance. Determination of corrosion initiation time of columns, evaluation of effects of corrosion on the reinforced concrete column at specific time intervals (0, 15, 30, 45, 60, 75 and 90 years), moment-curvature analysis of bridge column based on modified stress-strain relationship of materials and pushover analysis of bridge in longitudinal and transverse directions in order to determination of capacity curve of bridge at mentioned time points were the major steps and contribution of this research.

Corresponding author, E-mail: rahai@aut.ac.ir

Results show the degradation of bridge seismic capacity with time under corrosion. According to obtained results, in order to ensure the long-term seismic performance of reinforced concrete bridges in corrosive environments, the percentage increase of design base shear has been proposed.

### 2- Effects of corrosion on the materials

Corrosion initiation time of bridge columns was calculated based on the research done in Persian Gulf region [9]. Corrosion levels of longitudinal and transverse reinforcements have been shown in Figure 1. Effects of corrosion on the reinforced concrete section include the softening of cover concrete, degradation of strength and ductility of core concrete and degradation of steel mechanical properties considering bonding deterioration between concrete and steel.

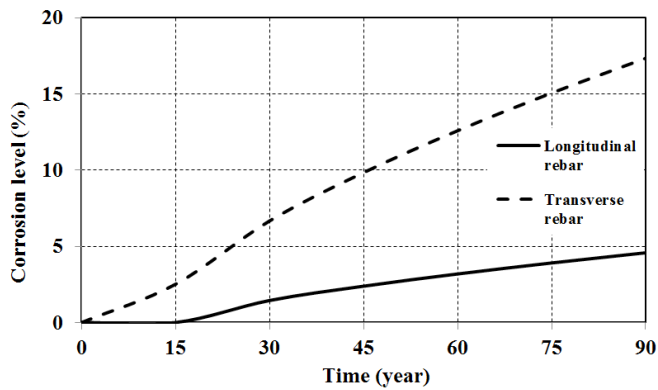


Figure 1. Corrosion level of longitudinal and transverse reinforcement

### 3- Moment-curvature and pushover analysis

Moment-curvature and pushover analysis of selected reinforced concrete bridge was done based on the flowchart shown in Figure 2. Results of moment-curvature and pushover analysis have been shown in Figure 3 and 4, respectively.

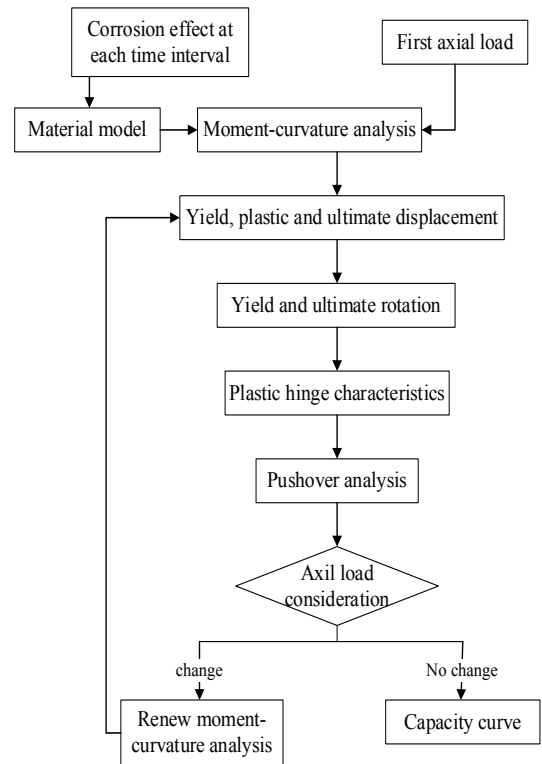


Figure 2. Pushover analysis procedure considering corrosion effect

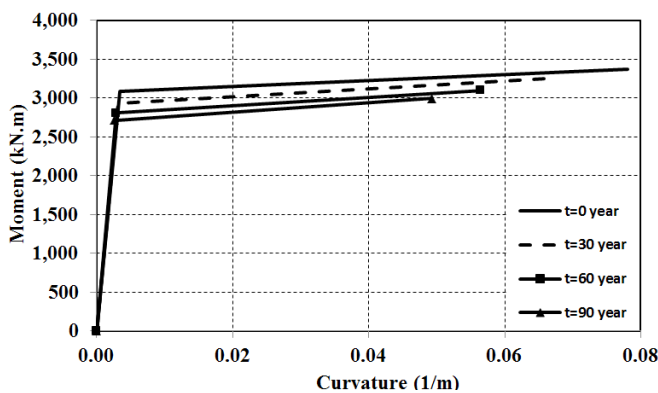


Figure 3. Moment-curvature diagram of corroded reinforced concrete column

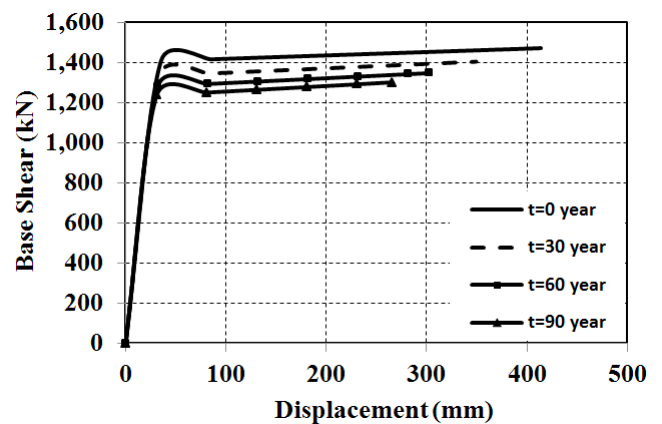


Figure 4. Longitudinal capacity curve of corroded RC bridge

#### 4- Conclusions

The following conclusions were drawn by analysis of obtained results:

1. Transverse reinforcement corrosion starts earlier compared to longitudinal reinforcement due to its thinner cover concrete.
2. Results indicate the degradation of material properties include core and cover concrete, steel and bonding between concrete and steel under corrosion.
3. Moment-curvature analysis shows that yield and ultimate moment and corresponding curvatures, energy per length, plastic rotation capacity and curvature ductility decreased due to corrosion.
4. Pushover analysis results show the degradation of the capacity curve of the bridge under corrosion state. In other words, we can say that strength and ductility of bridge decrease under corrosion state.
5. Based on obtained results, in order to ensure the long-term seismic performance of reinforced concrete bridges under corrosive environment within 90 years, 12.5% increase of design base shear has been proposed.

#### References

- [1] Li, C.Q., and Zheng, J.J., 2005. "Propagation of reinforcement corrosion in concrete and its effects on structural deterioration". *Magazine of Concrete Research*, 57(5), Jun, pp. 261-71.
- [2] Shi, X., Xie, N., Fortune, K., and Gong, J., 2012. "Durability of steel reinforced concrete in chloride environments: An overview". *Construction and Building Materials*, 30, May, pp. 125-138.
- [3] Coronelli, D., and Gambarova, P., 2004. "Structural assessment of corroded reinforced concrete beams: modeling guidelines". *Journal of Structural Engineering*, 130(8), Aug, pp. 1214-24.
- [4] Lee, H.S., and Cho, Y.S., 2009. "Evaluation of the mechanical properties of steel reinforcement embedded in concrete specimen as a function of the degree of reinforcement corrosion". *International journal of fracture*, 157(1-2), May, pp. 81-8.
- [5] Castel, A., Khan, I., and Gilbert, R.I., 2015. "Development length in reinforced concrete structures exposed to steel corrosion: A correction factor for AS3600 provisions". *Australian Journal of Structural Engineering*, 16(2), May, pp. 89-97.
- [6] Ou, Y.C., Fan, H.D., and Nguyen, N.D., 2013. "Long-term seismic performance of reinforced concrete bridges under steel reinforcement corrosion due to chloride attack". *Earthquake Engineering & Structural Dynamics*, 42(14), Nov, pp. 2113-27.
- [7] Ghosh, J., and Padgett, J.E., 2010. "Aging considerations in the development of time-dependent seismic fragility curves". *Journal of Structural Engineering*, 136(12), Jun, pp. 1497-511.
- [8] Zhong, J., 2008. "Seismic fragility estimates for corroded reinforced concrete bridge structures with two-column bents". PhD Thesis, Texas A&M University, Texas, Dec.
- [9] Ashrafi, H.R., and Ramezani-pour, A.A., 2007. "Chloride ion diffusion modeling of concrete containing silica fume based on experimental results". PhD Thesis, Amirkabir University of Technology (Tehran polytechnic), Tehran, Iran.

Please cite this article using:

M. R., Seify Asghshahr, A. R., Rahai, Pushover Analysis of Reinforced Concrete Bridges under Chloride-Induced Corrosion. *Amirkabir J. Civil Eng.*, 50(1) (2018) 73-88.  
DOI: 10.22060/ceej.2016.863



