An Analytical Study on Low Cycle Fatigue Assessment for Thick Walled Steel Pier

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1. Introduction

Under seismic loading, steel piers undergo large strain fluctuations of typically one to tens cycles. And low cycle fatigue (LCF) fracture at the base end of steel piers is one of the failure modes. It was already observed in the Great Hanshin Earthquake (1995), which raises concerns about their performance in future earthquakes. However, researches on the LCF of civil structures are limited and design guidelines have not been established. In this investigation, nonlinear dynamic analysis has been used to study the local behavior of steel piers under strong ground motions recorded at different sites. The purpose of the FEM analyses was to assess the low cycle fatigue life of steel pier by identifying the local strain at weld toe.

2. Proposed LCF assessment method

Revised Coffin-Manson relation was proposed to relate total strain amplitude with fatigue life. In the previous research, LCF strength curves of weld deposit, HAZ and base metal were obtained by a newly developed image-based system. Miner's rule is employed to evaluate structures subjected to variable amplitude loading.

A relationship between local strain range and average strain range over effective failure length was proposed by former research [1) 2)]. The equations are presented in Table 1. Local strain range at weld toe is denoted by $\Delta\varepsilon_r$ and average strain range over effective failure length is denoted by $\Delta\varepsilon_a$. A detailed description of effective failure length can be found in reference [3)]. Then, the local strain can be obtained through just calculating average strain by beam element model.

Table 1 Equations for strain range ratio

Equation	$\Delta\varepsilon_r / \Delta\varepsilon_a = a\Delta\varepsilon_a + b$	
Weld toe radius (mm)	a	b
0.2	-316.6	30.1
0.5	-122.8	15.7
1.0	-75.5	11.1
2.0	-42.1	7.5

3. Dynamic analysis

A total of nine modified earthquake acceleration time histories recorded in Hanshin earthquakes, which are Level-II design accelerograms representing major earthquake excitations recommended by Japanese Code, are used in this study. The earthquake ground motions are divided into three groups according to the local site conditions at the recording stations.

The dimensions of analyzed models are shown in Fig. 1 and listed in Table 2. A bilinear constitutive model with 400MPa yielding stress and $2\text{x}10^5 MPa$ young's modulus was adopted with a density of $7.86\text{x}10^3 kg/m^3$. Poisson's ratio was 0.3 and strain-hardening ratio was assumed as 1/100. The kinematic hardening was used with von Mises yield criterion. Two-node three-dimensional beam elements of type 25 provided in the MSC.Marc soft package were employed. For box sections, 28 integration points are set. Self-weight and P-δ effects were considered during analysis. For all the dynamic analyses in this study, 1% mass damping ratio was assumed and Newmark β method incorporated in Marc was resorted to for solution.

4. Results

Local strain is closely related to the weld toe radius. Radaj [4)] proposed a fictitious radius that is generally assumed as 1mm in the worst case. In this study, 1mm was also adopted for all cases. Rain-flow cycle counting technique is used to

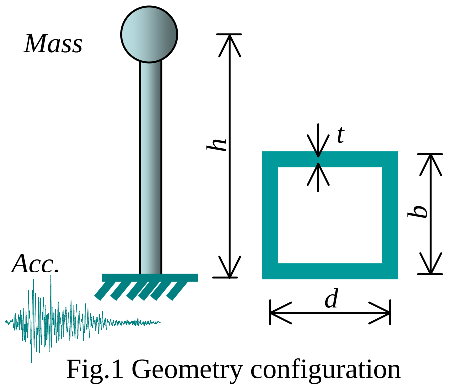

Fig.1 Geometry configuration

Table 2 Parameters of models

No.	R_f	$\bar{\lambda}$	h *	b*	d*	t*	P/P_y
U3	0.2118	0.3068	400	108	88	12	0.1406
U5	0.2451	0.4306	775	125	125	12	0.1103
U6	0.2451	0.3056	550	125	125	12	0.1429
U9	0.3268	0.3062	550	125	125	9	0.1470

*Unit: *mm*

obtain a histogram of cycle counts for the magnitude range of the cycles. Then it can be converted to local strain range based on Table 1. Damage indices *DI* can be obtained by Miner's rule. When damage index attained 1.0, steel pier is assumed failed due to low cycle fatigue.

The maximum average strain ratio based on beam element versus damage index was plotted in Fig. 2. It is demonstrated that maximum average strain ratios of failure vary from 8.81 to 35.08. For the damage indices less than 1.0, the maximum strain ratios vary in the range with an upper bound of 16.40. Various results exist for different excitations. For accelerograms of group I, all damage indices exceed 1.0 and corresponding strain ratios locate in a small range; for group II accelerograms, strain ratios scattered; for group III, the strain ratios locate in left side and most of damage indices are less than 1.0. For safety consideration, it is probably applicable to set the lower bound of strain ratio of failure as the threshold of low cycle fatigue. However, only one kind of weld toe radius was considered. The general conclusions cannot be drawn at present.

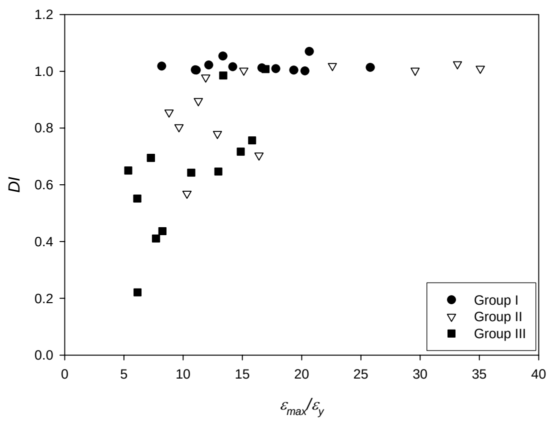

Fig. 2 Damage indices versus average strain ratio(r=1*mm*)

5. Conclusion

It is believed that this study provides further information towards the evaluation of low cycle fatigue failure. Following observations can be drawn: (1) Inelastic dynamic analyses showed that steel piers maybe failed due to LCF. Through several case analyses, damage indices were calculated by local strain based on the relationship between average strain over effective failure length and local strain. (2) Different groups of accelerograms yielded out various results. For safety consideration, the lower bound of maximum strain ratios or relative displacements probably can be assumed as the threshold value to prevent LCF failure.

6. References

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