

DYNAMIC CHARACTERISTICS OF WELDED STRUCTURE

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ABSTRACT

Welding is widely used for joint of many structures. In this paper, effect of welding on dynamic characteristics is examined based on experiment. First, dynamic characteristics of simple specimens with welding are measured. Next, effect of welding on random vibration and reliability for first passage problem is examined by a theoretical method using an analytical model with response characteristics measured from experiment. Finally, applicability of obtained results to actual structure is examined by experiment using frame model. It is concluded that damping ratio increases when welding is used.

1. INTRODUCTION

Welding is widely used for construction of many structures. Experimental studies on dynamic characteristics of welded structure carried out (Wozney and Crawmer 1968). However, dynamic characteristics were qualitatively evaluated in these study. On reliability of welded structures subjected to external loading, many studies have been carried out on static strength and cumulative damage (Bush 1992). However, dynamic characteristics of welded structures subjected to random vibration such as earthquake, wind and wave loadings and effect of welding on reliability of such structures have not been clear.

Considering above mentioned points, aim of this paper is presenting effect of welding on dynamic characteristics of structures and that on response characteristics and reliability of structures subjected to random vibration. First, by an experiment using simple specimens, dynamic characteristics of specimen with welding are compared with those of specimen without welding. Next, using results obtained by experiment, effect of welding on response characteristics and reliability of structure subjected to random vibration is examined. Finally, by an experiment using a model of actual structures, applicability of obtained results to actual structures is examined.

2. ESTIMATION OF DYNAMIC CHARACTERISTICS BY EXPERIMENT

By an experiment using simple specimens, effect of welding on dynamic characteristics is examined. Method and results of experiment are shown in the following section.

2.1 Method of experiment

As specimens, cantilever models shown in Fig.1 are used. Four types of specimen size shown in Table 1 are selected. Material of specimen is the rolled steel for general structure (JIS SS41). Length of fixed part on shaker L_f is 100mm. This part is fixed by three bolts. Length from weld line to the center of the left hole L_w is 250mm. The following three types of specimens are used.

- (1) Specimen without welding
 - (2) Specimen welded by manual operation
 - (3) Specimen welded by the automatic acid carbon welding machine
- Groove shape is V type. Specimens are butt welded.

As dynamic characteristics, damping ratio ζ and natural frequency f_n for the first vibrational mode are estimated. f_n is obtained by the frequency sweeping method. ζ is obtained by the following three method.

(I) Logarithmic decrement δ is obtained by free vibration. Then, the formula $\zeta = \delta / 2\pi$ is used.

(II) Half power method, that is, frequencies f_1 and f_2 where amplitude on resonance curve is $1/\sqrt{2}$ times of peak amplitude are obtained. Then, the formula $\zeta = (f_2 - f_1) / 2f_n$ is used.

(III) Ratio of response amplitude to input amplitude at f_n is $1/2\zeta$. This relation is used.

In the frequency sweeping method, input amplitude is fixed as 1.0mm p-p. Amplitude of 2.0mm p-p is also used when it is needed.

2.2 Results of experiment

In Table 2, values of ζ and f_n estimated by experiment are shown. Results of specimen B' are that obtained for specimen B shaken by 2.0mm p-p input amplitude. Other cases are obtained for input amplitude of 1.0mm p-p. In this

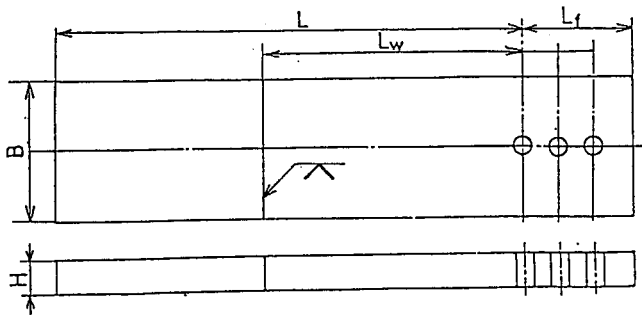


Fig.1 Shape of specimen

Table 1 Size of specimen (mm)

Specimen	L	B	H
A	530	65	9
B	530	65	6
C	460	65	9
D	460	65	6

Table 2 Damping ratio and natural frequency of specimen

Method	(I)		(II)		(III)		f_n (Hz)	f_{nw} / f_{nb}
	$\zeta (\times 10^{-3})$	ζ_w / ζ_b	$\zeta (\times 10^{-2})$	ζ_w / ζ_b	$\zeta (\times 10^{-2})$	ζ_w / ζ_b		
Specimen A	7.01		1.68		2.03		20.8	
B	7.56		5.20		0.97		15.4	
(1) B'	8.15		5.06		1.21		15.8	
C	5.72		1.84		1.62		27.2	
D	7.34		1.70		1.51		20.6	
A	8.20	1.17	2.10	1.25	2.17	1.07	21.4	1.03
B	8.88	1.17	5.06	0.97	1.07	1.10	15.8	1.03
(2) B'	9.38	1.15	5.31	1.05	1.27	1.05	16.0	1.01
C	6.94	1.21	2.02	1.10	1.72	1.06	27.2	1.00
D	7.60	1.04	1.94	1.14	1.53	1.01	20.6	1.00
A	7.50	1.07	2.14	1.27	2.12	1.04	21.0	1.01
B	9.06	1.20	5.31	1.02	1.10	1.13	16.0	1.04
(3) B'	9.28	1.14	5.00	0.99	1.29	1.07	16.0	1.01
C	7.85	1.37	1.83	0.99	1.77	1.09	27.4	1.01
D	9.20	1.25	1.68	0.99	1.59	1.05	20.9	1.01

table, ζ_w and ζ_b , f_{nw} and f_{nb} are damping ratio and naturel frequency for specimen with welding and that for specimen without welding, respectively. Values of ζ_w/ζ_b and f_{nw}/f_{nb} are shown in the right column of results for specimen with welding.

For damping ratio ζ , variation due to measuring method is seen. In most specimens, ζ_w is greater than ζ_b . ζ_w is about 10% greater than ζ_b . Difference due to welding methods is not clearly seen. Comparing results for specimen B with those for specimen B', ζ for specimen B' is about 5% greater than that for specimen B. ζ_w/ζ_b for specimen B' is less than that for specimen B.

For natural frequency f_n , in the greatest case of f_{nw}/f_{nb} , f_{nw} is 4% greater than f_{nb} . However, f_{nw} is almost same as f_{nb} in most cases.

In Table 3, mean value and coefficient of variation(COV) of ζ_w/ζ_b and f_{nw}/f_{nb} for specimen welded by manual operation and that welded by the automatic acid carbon welding machine are shown. In most cases, COV of ζ_w/ζ_b is less than 10%. Therefore, variation of ζ_w/ζ_b due to specimen size and input amplitude is relatively small. On the other hand, variation of f_{nw}/f_{nb} is very small since COV of f_{nw}/f_{nb} is about 1%.

3.EFFECT OF WELDING ON RANDOM VIBRATION CHARACTERISTICS

It is assumed that specimens are simulated by a single-degree-of-freedom system with ζ and f_n obtained by experiment. Effect of welding on response characteristics of specimen subjected to random acceleration input is examined.

Equation of motion with respect to displacement of mass relative to input point z is expressed as follows.

$$\ddot{z} + 2\zeta\omega_n\dot{z} + \omega_n^2 z = -\ddot{y} \quad (1)$$

where \ddot{y} is input acceleration and $\omega_n (=2\pi f_n)$ is natural circular frequency. As response, z is obtained which is related to deflection of specimens.

In this paper, standard deviation of z is examined when \ddot{y} is stationary white noise. Ratio of standard deviation for specimen with welding σ_{zw} to that for specimen without welding σ_{zb} is expressed as follows.

$$\frac{\sigma_{zw}}{\sigma_{zb}} = \sqrt{\frac{\zeta_b f_{nb}^3}{\zeta_w f_{nw}^3}} \quad (2)$$

In Table 4, obtained results are shown. Standard deviation is related to the maximum response. σ_{zw} is about 7% less than σ_{zb} .

4.EFFECT OF WELDING ON RELIABILITY

Effect of welding on reliability when structure is subjected to stationary white noise excitations is examined. In this paper, first passage problem is dealt with where failure occurs at instant when absolute value of response $|z(t)|$ first crosses tolerance level B_D . In this case, first passage probability is obtained by the following equation.

$$P_f(t) = 1 - \exp(-2\nu t) \quad (3)$$

where

$$\nu = \frac{1}{2\pi} \omega_n \exp\left(-\frac{B_D^2}{2\sigma_z^2}\right) \quad (4)$$

Tolerance level for specimen without welding B_{D_b} is determined by using σ_{zb} as follows.

$$B_{D_b} = n\sigma_{zb} \quad (5)$$

Effect of welding on reliability is examined by obtaining ratio of tolerance level for specimen with welding B_{D_w} to B_{D_b} for the case where P_f for specimen with welding is equal to that for

Table 3 Mean value and coefficient of variation of ζ_w/ζ_b and f_{nw}/f_{nb}

Method	(I)	(II)	(III)	
Specimen	ζ_w/ζ_b	ζ_w/ζ_b	ζ_w/ζ_b	f_{nw}/f_{nb}
(2) mean	1.15	1.10	1.06	1.01
cov	0.050	0.085	0.028	0.013
(3) mean	1.20	1.05	1.08	1.02
cov	0.084	0.104	0.031	0.012

Table 4 Ratio of standard deviation $\sigma_{z_w}/\sigma_{z_b}$

Method Specimen	(I)	(II)	(III)
A	0.885	0.856	0.924
B	0.885	0.969	0.913
(2) B'	0.918	0.962	0.961
C	0.908	0.953	0.971
D	0.982	0.935	0.996
A	0.953	0.873	0.964
B	0.861	0.932	0.888
(3) B'	0.923	0.991	0.955
C	0.841	0.989	0.941
D	0.880	0.992	0.963

Table 5 Ratio of tolerance level B_{D_w}/B_{D_b} (n=1)

Method Specimen	(I)	(II)	(III)
A	0.910	0.881	0.951
B	0.910	0.997	0.939
(2) B'	0.927	0.961	0.971
C	0.908	0.953	0.971
D	0.982	0.935	0.996
A	0.962	0.882	0.974
B	0.894	0.968	0.923
(3) B'	0.933	1.000	0.965
C	0.850	0.998	0.951
D	0.888	1.000	0.972

specimen without welding. B_{D_w}/B_{D_b} is obtained by the following equation.

$$\frac{B_{D_w}}{B_{D_b}} = \sqrt{\frac{2 \zeta_b f_{nb}^3}{n^2 \zeta_w f_{nw}^3} (\log \frac{f_{nw} + n^2}{f_{nb} + 2})} \quad (6)$$

In Table 5, results for n=1 are shown. B_{D_w} is about 5% less than B_{D_b} . This means that P_f for specimen with welding

is lower than that for specimen without welding for the same value of tolerance level.

Next, in order to examine effect of n, mean value of B_{D_w}/B_{D_b} is shown in Fig.2. When n is less than about 2, B_{D_w}/B_{D_b} decreases as n increases. When n is greater than about 2, B_{D_w}/B_{D_b} is about 0.935. When n is less than about 0.3, B_{D_w}/B_{D_b} is greater than 1. Therefore, when n is greater than about 0.3, P_f for specimen with welding is less than that for specimen without welding.

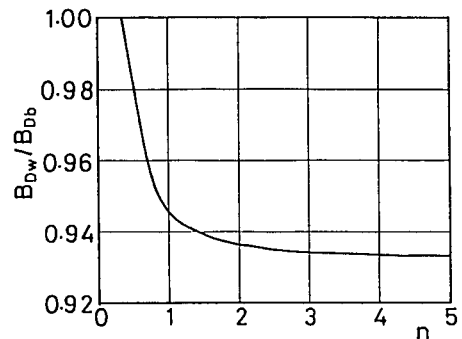


Fig.2 Ratio of tolerance level B_{D_w}/B_{D_b}

5.APPLICATION TO ACTUAL STRUCTURES

Applicability of results obtained in Chapter 2 to actual structures is examined by an experiment. Frame model shown in Fig.3 is used. This model is shaken in horizontal direction. Input amplitude is 0.5mm p-p. From this experiment, damping ratio and natural frequency for the first vibrational mode are measured by method shown in Chapter 2. Welding is done by the automatic acid carbon welding machine. Three types of models are used.

- (a) Model without welding
- (b) Model of which one column is welded
- (c) Model of which two columns are welded

Length from weld line to bottom of column is 210mm.

In Table 6, obtained results are shown. Damping ratio of model with

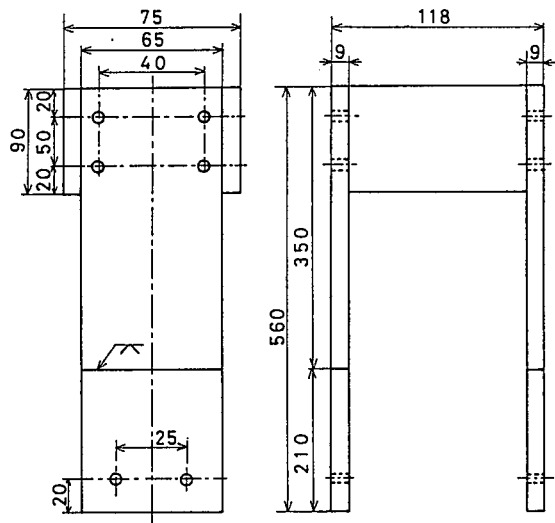


Fig.3 Frame model

Table 6 Damping ratio and natural frequency of frame type model

Method	(I)		(II)		(III)			
Specimen	$\zeta(\times 10^{-3})$	ζ_w/ζ_b	$\zeta(\times 10^{-2})$	ζ_w/ζ_b	$\zeta(\times 10^{-2})$	ζ_w/ζ_b	f_n (HZ)	f_{nw}/f_{nb}
(a)	7.47		1.48		2.84		22.0	
(b)	8.46	1.13	1.55	1.05	3.36	1.18	22.6	1.03
(c)	8.88	1.19	1.59	1.07	3.25	1.14	22.0	1.00

welding is about 10% greater than that of model without welding. Damping ratio of model(c) is greater

than that of model(b), but difference is very small. Natural frequencies of these models are almost same. Therefore, results obtained in Chapter 2 are expected to be applied to actual structures.

6. CONCLUSIONS

By an experiment using simple specimens, dynamic characteristics of specimen with welding is compared with those of specimen without welding. Then effect of welding on response characteristics and on reliability are examined. Obtained results are summarized as follows.

(1) Damping ratio of specimen with welding is almost 10% greater than that of specimen without welding.

(2) Natural frequency of specimen with welding is almost same as that of specimen without welding.

(3) When specimen is subjected to stationary white noise excitation, standard deviation of specimen with welding is smaller than that of specimen without welding.

(4) When specimen is subjected to stationary white noise excitation, first passage probability for specimen with welding is lower than that for specimen without welding.

(5) By an experiment using frame model, damping ratio becomes greater when column of model is welded. So, obtained results are expected to be applied to actual structures.

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