A NEW METHOD OF EVALUATING SEISMIC STABILITY OF STEEL PILE STRUCTURES

by

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SYNOPSIS

A steel piled wharf, unlike other type of quaywalls, has high flexibility and carrying out earthquake-resistant design of this type of wharf by the seismic coefficient method as with other structural types has been subject question. By the investigation of the restoring force characteristics of these wharves including the plastic ranges of steel piles through experiments, confirms that the wharves may be replaced by vibrating systems of one degree of freedom, and the hysteretic restoring force characteristics of the wharves can be explained by the PHRI Method for lateral resistance of piles and the expression for general hysteretic restoring force suggested by P. C. Jennings. Following this, earthquake response analyses of these vibrating models are carried out and elasto-plastic responses of steel piled wharves are found. Based on the results obtained, a new method of evaluating seismic stability of piled wharves is proposed.

INTRODUCTION

In recent years, large number of steel piled wharves using steel pipe piles as vertical piles have been constructed among steel pile structures at port and harbour works in Japan. This type of structures has such many advantages as easiness of construction, shortening of construction period, low cost for field works, and validity of being constructed even in somewhat soft ground.

These steel pile wharves have been designed based on the seismic coefficient method, as the other port and harbour structures. The seismic coefficient method, however, should be originally applied to the rigid structures which vibrates same as the foundation. It might be in principle contradict to apply this method to such flexible structures as vertical piled wharves which have the natural period of approximately one second. Therefore, these structures must be designed in consideration of seismic response.

However, these structures have high response factor corresponding to vibration of ground, it being uneconomical to confine working stress within the region of elasticity of steel material.

In this paper was proposed the new evaluation index for seismic resistance due to the following process; seismic response including the

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region of plasticity of steel material was taken into consideration, response value was compared with analized results of displacement and load of vertical piled wharves subjected to horizontal force at the ultimate stage.

RESTORING FORCE CHARACTERISTICS OF STEEL PILE WHARF

Many research works on piled structures subjected to static and dynamic horizontal load have been carried out so far. Those, however, were concerned with the behavior of elastic stage of steel material, and no information has been obtained through experiments on behavior at the stage where steel exceeds its yield point.

Because of this situation, a full-sized model of a piled wharf was constructed at Port of Shimizu, and loading test and vibration test were conducted at the loading range in which stress of material exceeded yield point.

It has been evident that restoring force characteristics obtained experimentally can be expressed with the expression which was proposed by P. C. Jennings.

EARTHQUAKE RESPONSE OF STEEL PILED WHARF

A steel piled wharf can be replaced to an extremely simple vibration model, except for the fact that the restoring force characteristics of piles is non-linear. Nine cases of earthquake records, were adopted for the response snalysis. Fig. 1 indicates one example of response analysis. This case was obtained by means of inputting the seismic record of Port of Hachinohe at the time of Tokachioki Earthquake. Natural period of elastic system was set at 1.0 second which was same at that corresponding to the vicinity of yield point for non-elastic structures. Damping coefficient for elastic response was 5 percents. As for damping of non-elastic system, only hysteresis damping was considered.

Fig. 2 shows response spectra in order to evaluate the general trend of absolute acceleration response. In linear system, damping coefficient considered was the three values of 0 percent, 5 percents and 10 percents. On the contrary, input level was varied in the case of non-linear system. Namely, a_y means acceleration corresponding to the load at which the member yields, and a_o means maximum seismic acceleration. That is, the apparent damping coefficient increases the more the level of the input acceleration relatively raises compared to strength of member.

Response displacement was analyzed as for nine cases of earthquake records. Fig. 3 indicated one example of the relationship between μ_r and $F_y/Y_y \cdot M$ in the case of $a_y/a_o = 1$. μ_r expresses response displacement in the form of ductility factor, and $F_y/Y_y \cdot M$ is corresponding to the square of natural circular frequency at yield point. The relation between μ_r and $F_y/Y_y \cdot M$ shown in the figure was averaged out, and similar operation was carried out for the other ratios of a_y/a_o. This result is shown in Fig. 4. According to this figure, $F_y/Y_y \cdot M$ and a_y are determined if the cross section of member of pile structure is decided. Further, maximum response displacement can be obtained in the form of μ_r after maximum acceleration a_o of input earthquake is determined.

ULTIMATE DISPLACEMENT OF STEEL PILED WHARF

As for ultimate displacement of steel piled wharf, fiber stress of head of pile which has the highest load-carrying rate first exceeds yield point according as the horizontal load applied to wharf increases. If load increases further, plastic hinge is produced at the cross section of head of pile. As load is applied further, plastic hinge is successively produced at the cross section of head of other pile or at the cross section of underground part of the first pile at which the maximum bending moment occurs. When plastic hinges occur at heads and parts of underground of all piles according to the process mentioned above and the wharf is no longer self-standing, this stage is considered to be the state of ultimate displacement.

SEISMIC STABILITY OF STEEL PILED WHARF

In Fig. 4, several examples of maximum seismic response displacement of public wharves having been constructed so far are plotted in the form of μ_r. It may be apparent from this figure that some cases show μ_r of less than unity. This fact means that pile members don't come up to yield point even if response is taken into consideration. Table 1 shows the ratio between ultimate displacement y_{cr} and displacement y_r of wharves in the form of the ratio of μ, Further is indicated the ratio F_{cr}/F_r which may be the concept of usual safety factor.

Through the method mentioned before, it has become possible to analyze maximum response displacement and ultimate displacement. However, safety factor must be distinct in considering the seismic stability of structures. Such factors as μ_r, μ_{cr}/μ_r and F_{cr}/F_r might be conceivable as the index of safety factor. If only the factor of μ_r is considered, the past fact only indicated that μ_r was less than 1.3 for the wharves having no damage of earthquake. It may make things uncertain that the results of response analysis using this method differ with the input seismic motion. Pertaining to this point, the result of response analysis is based on the average data and the ratio between the average data and the upper limit of 95 percents confidence limit is 1.2. In consideration of this approach, it may be concluded at the present stage that the ratio F_{cr}/F_r of approximately 1.3 to 1.4 is the adequate number of safety factor, even if other unknown factors are included.

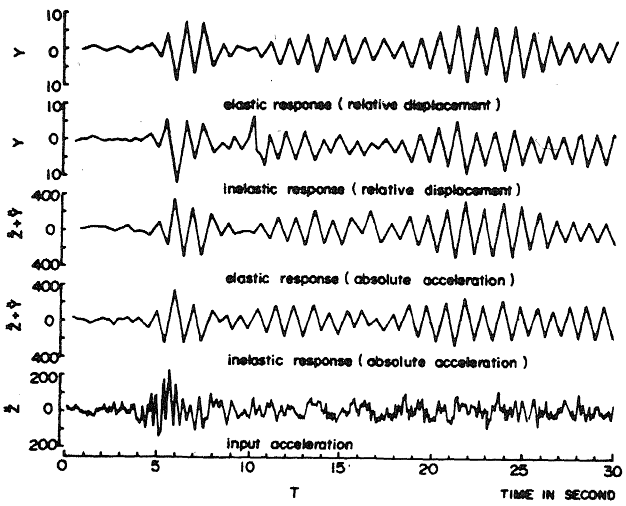

Fig-1 Earthquake response calculation of elastic and inelastic systems S-252(Hachinohe) N-S component

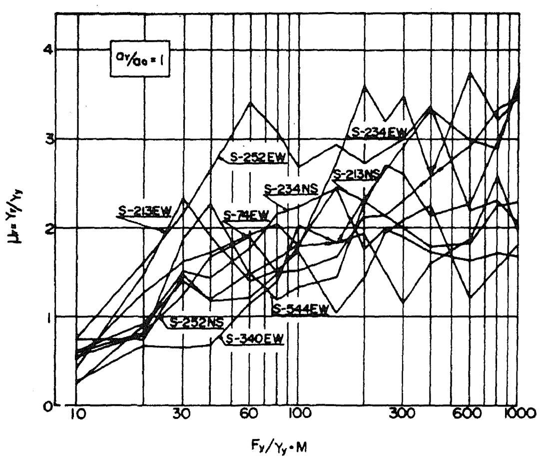

Fig-3 Relation between Fy/Yy·M and μr, when ay/ao=1

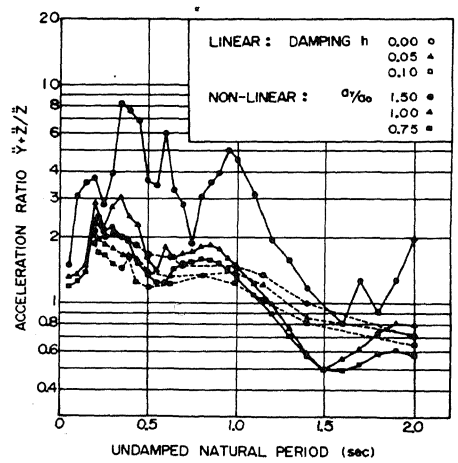

Fig-2 Linear and non-linear acceleration response spectra S-252(Hachinohe) N-S component

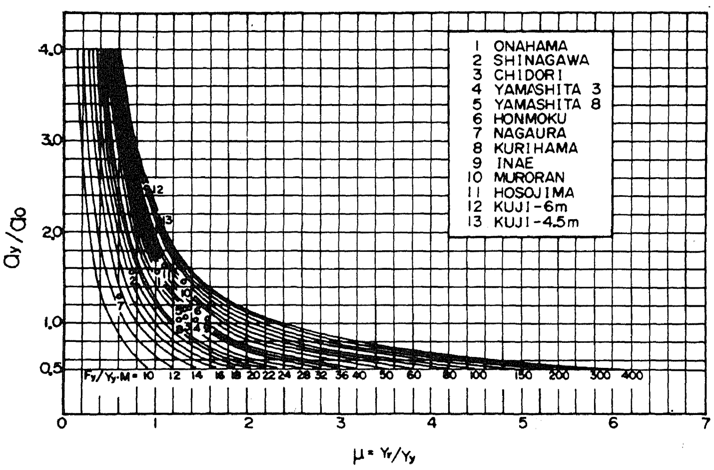

Fig-4 Generalized curves for μr, and μr-values for existing piled wharves

	W=M.g	a_o	$F_y/(Y_yM)$	a_y/a_o	μ_r	Y_r	F_r	Y_{cr}	F_{cr}	μ_{cr}/μ_r	F_{cr}/F_r
	ton		sec^{-2}			cm	ton	cm	ton		
Onahama	78.9	0.15	35.7	1.55	1.02	6.50	18.69	28.79	36.68	4.43	1.96
Shinagawa	184.8	0.20	18.8	1.56	0.74	12.02	46.04	56.82	106.88	4.73	2.31
Chidori	151.9	0.20	29.4	1.06	1.32	9.35	38.69	33.57	67.87	3.59	1.75
Yamashita-3	185.8	0.20	34.0	1.02	1.44	8.41	47.48	28.94	74.68	3.44	1.57
Yamashita-8	248.7	0.20	34.6	1.15	1.32	8.59	68.64	24.26	106.99	2.83	1.56
Honmoku	189.0	0.20	39.2	1.16	1.36	7.86	53.31	23.34	79.32	2.97	1.49
Nagaura	172.5	0.15	13.0	1.29	0.60	8.76	22.77	36.81	54.42	4.20	2.38
Kurihama	90.4	0.15	26.0	1.03	1.25	7.33	16.30	23,03	26.72	3.65	1.64
Inae	257.0	0.20	45.9	1.04	1.56	6.91	70.93	30.89	126.42	4.47	1,79

Table-1 New indices for safety factors of existing piled wharves in Japan