TESTS ON WELL FOUNDATION MODELS UNDER HORIZONTAL DYNAMIC LOADS

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SYNOPSIS

Free vibration tests and cyclic and repetitive lateral load tests were conducted on 15 cm and 20 cm square-section laboratory models, the main variables being magnitude of vertical load, depth of embedment and magnitude of skin friction on sides. A field model of square base with 1.5 m sides was also similarly tested. The frequency and damping values as influenced by the various parameters are presented.

INTRODUCTION

Wells or caissons are subjected to dynamic loads during earthquakes and their behaviour under such loads is not well known. In order to study the dynamic behaviour of wells, free vibration tests and cyclic and repetitive lateral load tests were conducted on 15 cm and 20 cm square laboratory models. Based on the field conditions usually encountered the main variables used were (i) the magnitude of vertical loads (Q_v), (ii) depth of embedment (D) and (iii) magnitude of friction on sides (rough or smooth). A reinforced field concrete model of base 1.5 m square was also tested in free vibrations in dry as well as saturated ground conditions.

TESTS PERFORMED

Laboratory tests were conducted in a 2.5 m x 1.25 m x 1.25 m deep tank having sand deposition facility by reinfall technique, vertical loading of well through a beam with knife edge support on well and roller support at the other end, and horizontal loading by a wire with weights placed on hanger as shown in Fig. 1. All test beds were of sand having mean grain size D_{10}=0.15 mm and uniformity coefficient C_u=1.90. The deposited density γ_d was found as 1.658 ± 0.005 g/cm^3 with relative density D_r=91.5% and ϕ_u=33.4°. The model was first set vertically on a formed bed and the sand was then deposited around it to the required depth of embedment. Coefficient of friction on vertical faces of well was changed from 0.66 (rough case) to 0.20 (smooth case) by using polythene sheets on the faces. Horizontal free vibrations were imparted by tapping on the axis of well. Acceleration vs time records of vibrating model were obtained using acceleration pick up, universal amplifier and ink writing oscillograph. Cyclic load tests were performed by applying the horizontal load first to the right, releasing gradually and then applying it to the left. Applied load was gradually increased and the cyclic process continued. Repetitive loads were half cycles of cyclic loads.

Results of free vibration tests performed on 15 cm and 20 cm models with the variation as (i) depth/width (D/B) ratio, (ii) vertical load (Q_v) and (iii) friction condition on sides are included in Table 1. Cyclic and repetitive lateral load test results are given in Table 2.

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Field tests were performed on a 1.5 m square section and 2.25 m deep reinforced concrete well. The test set-up and the ground conditions are shown in Fig. 2. The instrumented well was sunk into the ground by dredging at the base and sinking under vertical load. Various tests conducted and their results are given in Table 3. Horizontal free vibrations were produced by giving the well an impulse at its top with a sledge hammer. More details of test set up and test data are available elsewhere (Sharda 1975).

INTERPRETATION

Tests on small size wells were performed essentially to observe the simulated effect of two typical field conditions of embedment as follows on the vibrational behaviour

(i) "Light" well, that is a well in which self weight of well 'w' and the superimposed load Q_v are smaller than the skin friction resistance Q_s:

(ii) "Heavy" well in which $w + Q_v > Q_s$.

Typical free vibration records of 15 cm well are shown in Fig. 4. From such records for 15 cm and 20 cm wells, natural frequency (f_n) was directly read and the damping factor ξ was obtained by the logarithmic decrement method. (Thomson 1964). The values are recorded in Table 1. In this table, test Nos. 71, 74, 78, 81, 84, 88, 92, 96 and 100 present 'light' well condition and the remaining tests the 'heavy' well condition. It is observed from the f_n and values given in columns (5) and (6) of Table 1 (A), (B) and (C) that wells held by skin resistance only have higher frequency and damping than those in which skin resistance was overcome and more load was transferred to the base. The damping factors ξ in the 'light' wells are found to lie between 11.50 and 23% with an average value of 18.42%. In the case of heavy wells, the damping factor lies between 5.34 and 16.4% with an average value of 10.5%.

The reduction in frequency for 'heavy' wells as compared with 'light' wells may be attributed to the reason that the lateral stiffness decreases after skin friction has been fully mobilized since any load in excess of the total skin resistance would be transmitted to the soil below the well resulting in higher stresses making the soil behaviour nonlinear and of the softening type. It is also likely that larger soil mass may be participating in vibration leading to smaller natural frequency. Also the damping forces would be high due to friction in case of wells where loads are smaller than the total skin resistance of well. But once the extra damping force from the side is removed due to the application of larger vertical loads the damping will reduce as is observed in the case of heavy wells.

A typical lateral load vs. displacement diagram of a cyclic load test is shown in Fig. 3(a) and a repetitive load test in Fig. 3(b). It was observed from all tests that under all conditions of loading, embedment and side friction, the response of well is nonlinear and hysteretic. The loops show that considerable energy is dissipated in a cyclic motion. They also show that the tilt once acquired due to lateral loading becomes more or less permanent and there is very little elastic rebound. Table 2 shows the values of equivalent damping obtained from hystersis curves for different yield ratios. Damping constants were worked out by the method suggested by Hudson (1965). From the table it is observed that for high yield ratios (x_m/x_y) of 10.80 to 20, the damping varies from 6.43% to 4.26% and for low yield ratios of 2.81 to 9.35, it is from 7.08% to 8.83%.

Free vibration records of the field well model (Fig. 5) show that a higher mode of vibration is also present. This may be due to variation of soil properties around the well as well as the loading arrangements. Table 3 shows the results. The first natural frequency is of the order of 15 Hz and the damping factor varies from 7 to 15% as determined by the logarithmic decrement method.

CONCLUSIONS

Vibration of field wells is seen to be a complicated problem due to complex soil condition and loading conditions. Light wells held by friction only exhibit high damping, averaging about 18% and heavy wells are found to have lower damping averaging about 10%. In heavy wells the bed on which the well rests plays an important roll in its vibrational characteristics. The lateral stiffness of heavy wells is comparatively less.

ACKNOWLEDGEMENT

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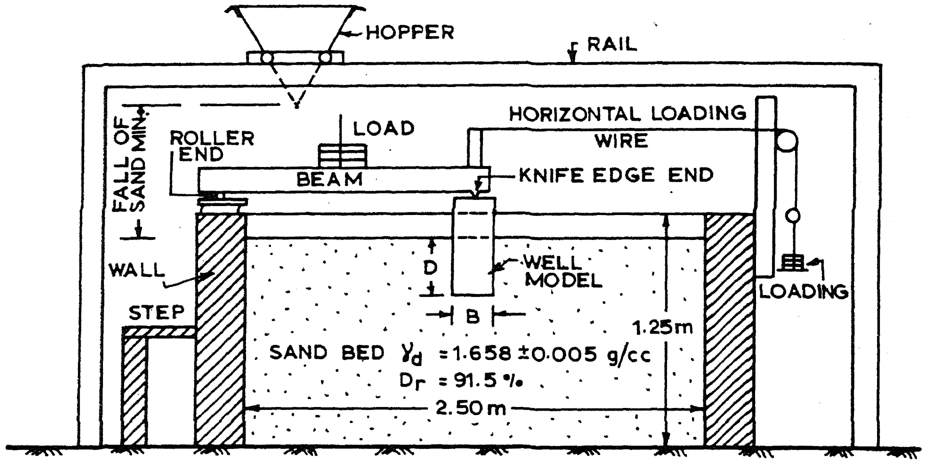


FIG. 1 _ LABORATORY WELL TESTING FACILITY

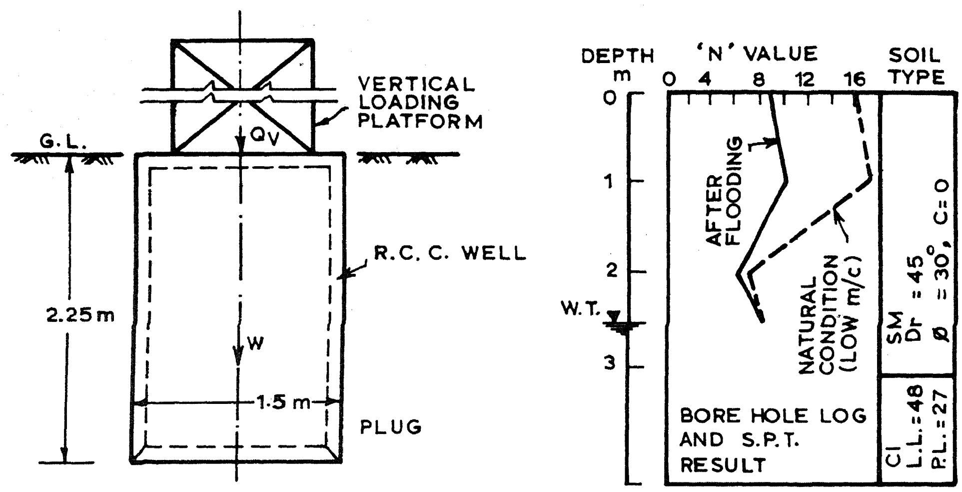
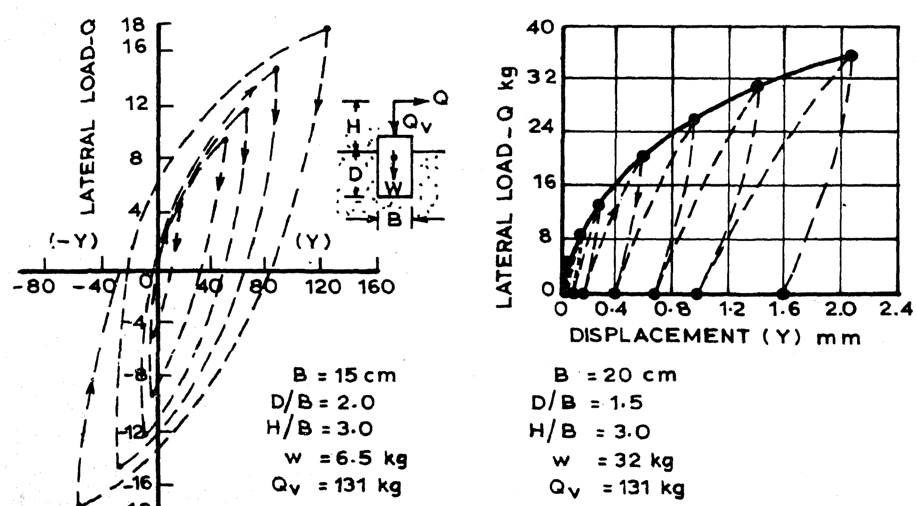


FIG. 2 _ FIELD WELL MODEL AND SOIL CONDITIONS



a_ Test no. 59 b_ Test no. 67

FIG. 3 _ TYPICAL CYCLIC AND REPETITIVE HYSTERITIC CURVES

TABLE 1 : Natural Frequency and Damping Factors of Laboratory Well Models in Free Vibration Tests

Test No.	D/B	Q_y kg	Q_s kg	f_n c/s	ξ %	Test No.	D/B	Q_y kg	Q_s kg	f_n c/s	ξ %
(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
(A) 15cm square model; Self weight (w) = 6.5 kg											
69	1.5	101	21	13.0	9.0	74	1.5	0	5.0	48.0	22.3
70	1.5	51	21	15.3	7.5	75	2.0	131	5.0	15.7	6.8
71	1.5	0	21	27.0	20.4	76	2.0	101	6.5	12.0	8.1
72	1.5	101	5	13.9	11.0	77	2.0	51	6.5	16.0	11.0
73	1.5	51	5	15.7	9.1	78	2.0	0	6.5	52.0	11.5
(B) 20cm - base mild steel model; w = 32 kg											
79	1.5	131	62	13.9	11.0	82	2.0	131	88	25.0	16.4
80	1.5	56	62	25.0	13.8	83	2.0	56	88	33.4	11.0
81	1.5	0	62	54.8	18.8	84	2.0	0	88	62.5	19.2
(C) 20cm - base wooden models; w = 12 kg											
85	1.5	131	42	12.5	7.5	93	2.0	131	60	25.0	11.0
86	1.5	71	42	15.7	5.3	94	2.0	71	60	17.9	6.4
87	1.5	31	42	25.0	9.3	95	2.0	31	60	29.8	10.3
88	1.5	0	42	62.5	17.5	96	2.0	0	60	50.0	13.8
89	1.5	131	10	10.4	14.6	97	2.0	131	12	12.5	12.4
90	1.5	71	10	13.9	9.1	98	2.0	71	12	17.9	13.6
91	1.5	31	10	20.8	16.0	99	2.0	131	12	12.5	11.0
92	1.5	0	10	62.5	23.0	100	2.0	0	12	62.5	20.8

Q_v = Superimposed vertical load, Q_s = Skin resistance (kg),
f_n = Natural frequency, ξ = Damping factor

TABLE 2 : Damping Factors from Cyclic and Repetitive Lateral load Tests on Laboratory Models

Test No.	B cm	w kg	D/B	Q_v kg	Faces	Q_m/Q_y	x_m/x_y	ξ %
59	15 @	6.5	2.0	131	R	2.50	6.30	7.54
60	15 @	6.5	2.0	131	R	2.92	8.06	8.83
61	15 @	6.5	2.0	131	S	2.18	4.18	7.93
62	15 @	6.5	2.0	101	S	2.50	5.63	7.84
63	15 @	6.5	2.0	0	R	2.67	11.30	6.16
64	20 @	12.0	1.5	131	R	2.00	2.81	7.08
65	20**	32.0	1.5	131	R	2.50	9.35	7.82
66*	20**	32.0	1.5	156	R	2.92	17.45	4.90
67*	20**	32.0	1.5	131	R	2.92	10.80	6.43
68*	20**	32.0	1.5	56	R	2.75	20.00	4.26

** = Mild steel model; @ = wooden model; w = self wt. of model;

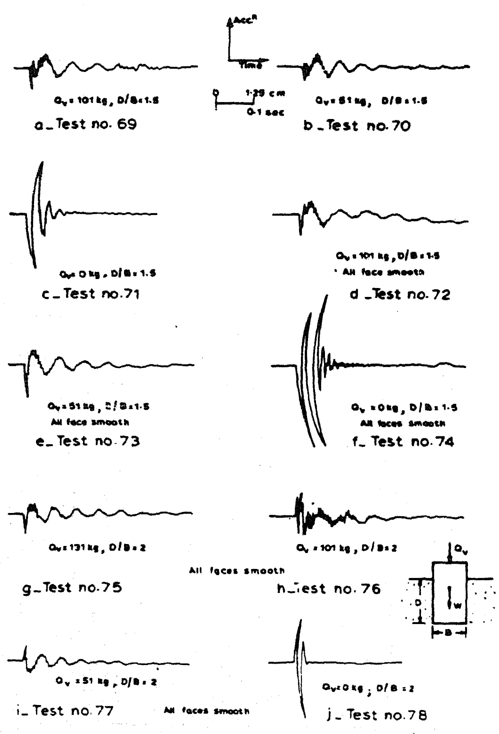
R = rough; S = Smooth; * = Repetitive load tests; Q_m, x_m are max. force and displacement; Q_y, x_y are characteristic force and displacement.

TABLE 3 : Free Vibration Tests on Field Model

X - section = 1.5m x 1.5m, D = 2.25m, w = 6.5 tonnes

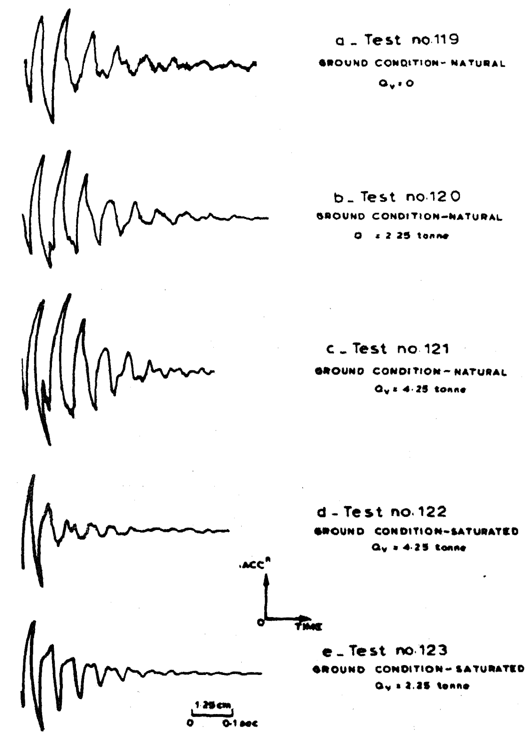
Test No.	Q_v t	Soil Condition	f_n Hz	ξ %
119	0	Natural	13.78	9.1
120	2.25	Natural	15.12	15.2
121	4.25	Natural	16.65	7.2
122	2.25	Saturated	17.85	15.3
123	4.25	Saturated	18.15	7.2

Q_v = superimposed load in tonne; f_n = natural frequency
ξ = damping factor;



FREE VIBRATION RECORDS (Acceleration vs time) of 15cm well model

FIG. 4



FREE VIBRATION RECORDS OF FIELD MODEL (Test no. 119 to 123)

FIG. 5