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Characterization and performance at the reclaimed island of Rokko in Kobe

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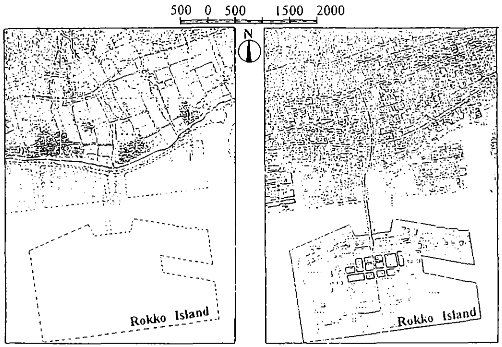
ABSTRACT: The paper deals with the site characterization initiatives at one of the large scale land reclamation sites in Kobe in the light of the Hyogoken-Nambu earthquake experience. The challenges involved with characterization of reclaimed site for a large scale development project in a seismically active zone is highlighted. Attempt is made to relate the site characterization efforts to the long-term monitoring after land reclamation and the effectiveness of the ground improvement initiative.

1 INTRODUCTION

Reclaimed ground conditions present unique challenges for site characterization, specially when the site is in a seismically active area. One of the heavy concentration of reclaimed land in Japan can be found at the port city of Kobe, located in the Osaka bay about 500km west of Tokyo. Owing to the narrow natural flat ground, the seaward expansion of Kobe city started early on, and can be traced back to several hundred years. Two major land masses reclaimed in recent times are Port island and Rokko island. Reclamation of the 580ha (1433 acres) Rokko island started around 1973 and was completed in 1993. The extent of the urban growth and the reclamation activity around Rokko island over the past 100 years can be seen in Fig. 1.



Map of the area from around 1885
Present situation in the same area

FIG. 1 Land reclamation around Rokko island

Considering the potential seismic activity in the region, a conscious effort was made in selecting a suitable fill material. The selected material was considered to be competent, well graded and resistant to large scale liquefaction during strong ground shaking. The magnitude 7.2, January 17, 1995 Hyogoken-Nambu earthquake in Kobe tested these initiatives to the limit. This paper summarizes the site characterization and monitoring efforts undertaken as part of the city core development project in the central part of Rokko island. Attempt is made to provide a prediction *visavis* performance case study in conjunction with the long term monitoring after reclamation and the efficacy of the soil improvement methods utilized.

2 GENERAL GEOLOGICAL FEATURES

The city of Kobe is located at the foot of the Rokko mountain system (Fig. 2), believed to be created by thrust movements primarily along east-west and northwest-southeast directions, resulting in the development of several active faults at the boundaries. The narrow and oblong coastal plain at the foot of the mountain consists of a complex combination of alluvial fans formed by several small streams flowing into the bay. Rokko island itself looks like an extension of the alluvial fan formed by the Sumiyoshi river in Fig. 2. The geological structure in this region consists of very deep and complex sedimentary formations overlying the mainly granite basement at depths of a kilometer or more.

It is clear that the residual consolidation settlement yet to occur is much larger in unimproved ground than in improved ground. The residual settlement was mostly in the range of 10 to 40cm in the improved ground, while it varied from 60 to 260m in unimproved ground. Primary reason for the variation in S from point to point is the variation in H itself.

The residual settlement was noted to be small and generally uniform in blocks B1 to B4 (Fig. 3). There was larger variation in case of the blocks on the west side, owing to the variation in H. However, considering the stiffness of the very thick fill layer, large undulation in the resulting surface settlement was not expected even at locations of substantial variation in S at relatively close proximity. This was found to be the case from observation and monitoring.

4.1 *Change in Residual Settlement in Three Years*

As noted above, various investigations for the site characterization were carried out over a period of four years. In this process, investigations for residual settlement evaluation were carried out twice in blocks A2 and B2 with an intervening period of three years. The results are compared in Table 1, where the results based on investigation made in April 1988 and April 1991 are compared. The trend of decreasing residual settlement is clearly illustrated.

4.2 *Long Term Monitoring of Settlement*

A dense array system was installed in blocks A5, A6, B4 and B5 for long term monitoring of the surface settlement. In addition, some vertical array were installed for evaluation of the distribution over depth of the time-dependent settlement observed at the surface. The progress of the consolidation settlement of the alluvial clay layer being continuously monitored since June 1988 is shown in Fig. 7, where the vertical dotted line indicated the date of occurrence of the Hyogoken-Nambu earthquake. No significant change in the trend of the settlement progress due to the earthquake can be noted. The detailed analysis of the effect of earthquake shaking on the total ground settlement and its distribution into different layers is being published elsewhere.

Table 1. Change in residual settlement in three years

	A2					
	North side		Central part		South side	
	Apr.88	Apr.91	Apr.88	Apr.91	Apr.88	Apr.91
H (m)	12.45	11.4	16.8	18.75	10.45	7.36
Wn (%)	71.5	67.7	75.7	71.3	70.5	53.3
S (cm)	48.3	12.5	153.4	82.3	33.0	0.0
S/H (%)	3.9	1.1	9.1	4.4	3.2	0.0

	B2			
	North side		South side	
	Apr.88	Apr.91	Apr.88	Apr.91
H (m)	11.2	10.65	14.1	11.3
Wn (%)	68.8	66.8	77.8	68.8
S (cm)	8.8	0.0	54.3	8.8
S/H (%)	0.8	0.0	3.9	0.8

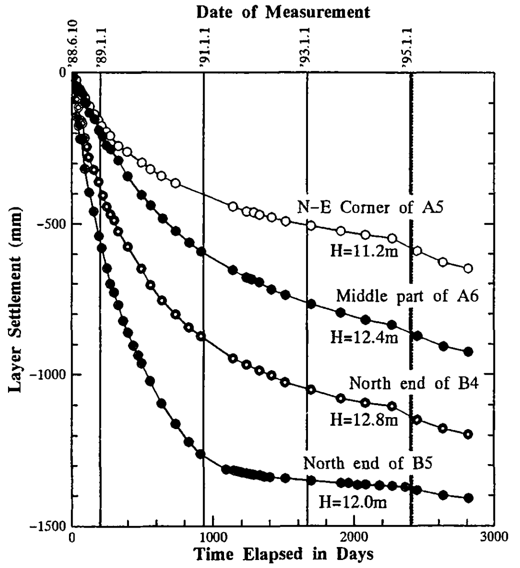


FIG. 7 Result of the long term settlement monitoring

The total settlement during the first three year of the monitoring can be found to be 45 to 130cm from Fig. 7, indicating significant variation depending on the location. The difference in computed residual settlement S between the three year interval given in Table 1 varies from about 9cm (North side of B2) to 71cm (central part of A2) indicating similar large variation depending on the location.

5 DYNAMIC CHARACTERISTICS

Considering the apparent seismic hazard of the area, particular attention was given to investigations for evaluating the dynamic characteristics of the site. Extensive field and laboratory tests were undertaken for this purpose, of which the P-S logging, microtremor measurement and dynamic deformation tests were of primary consideration. Results of P-S logging and dynamic deformation tests are briefly described in what follows.

5.1 *P-S Logging for Vs and Vp profiles*

The tests for evaluating the profiles of S-wave velocity Vs and the P-wave velocity Vp were carried out at seven locations, one each in blocks A1 to A4, B1 and B2. Most of the tests were carried out to a depth of 110m, and both P and S waves were measured at 1m interval. The results of the investigation are summarized in Table 2, where the layer designations (F, Ac etc.) correspond to those in Figs. 4 and 5.

It can be noted in Table 2 that both Vs and Vp change at about 5m depth in the fill layer. The P-wave velocity Vp of fill material within the 5m depth is much smaller than that of water (Vp of water is 1500m/s). This is an indication that the free water surface at the site is about 5m deep. The S-wave velocity Vs of 330 to 350m/s of the fill material deeper than 5m is comparable to the diluvial layers underlying the soft clay layer, indicating a well compacted material.

From the Vs profile of the ground thus obtained, the elastic amplification characteristics of the ground was analyzed based on the theory of multiple reflection of SH waves. The computed amplification characteristics at ground level relative to a depths of about GL-98m for block B2 is given in Fig. 8 as a typical case. From such analysis, it was seen that the fundamental period of the ground is about 1.2 to 1.5 seconds. This range of the period was also confirmed by microtremor measurements as well, and is considered a reasonable value for similar reclaimed sites in Japan.

Fig. 9 shows the response spectra of the two horizontal components of the free field motion recorded at the project site during the Hyogoken-Nambu earthquake. Comparison with Figs. 8 shows some interesting resemblance of the amplification characteristics, specially with respect to the EW component.

Table 2. Layer-wise distribution of Vs and Vp

Layer	Thickness (m)	Vp (m/sec)	Vs (m/sec)	Poisson's Ratio	E (Mpa)
F	4~5	430~650	170~300	0.237~0.366	145.2~522.9
	18~21.4	760~1100	330~350	0.365~0.451	452.2~886.8
Ac	9.2~14.1	950~1540	150~200	0.477~0.497	104.0~203.1
Dal	6.9~13.4	920~1540	220~300	0.436~0.487	245.3~529.7
	27.4~36.5	1100~1950	300~430	0.410~0.485	507.2~990.8
Dcl	13.5~24.4	1100~1750	260~290	0.468~0.486	320.8~399.3
Da2	7.2~13.0	1400~2280	410~430	0.448~0.483	764.2~1020.2
Dc2	11.8	1400~2000	300~380	0.467~0.488	575.8~807.4
Da3	5.0	1600	470	0.453	1216.4

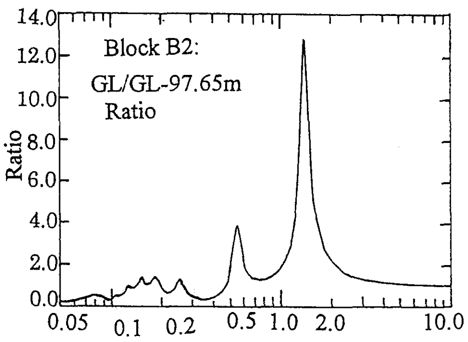


FIG. 8 Amplification ratio characteristics

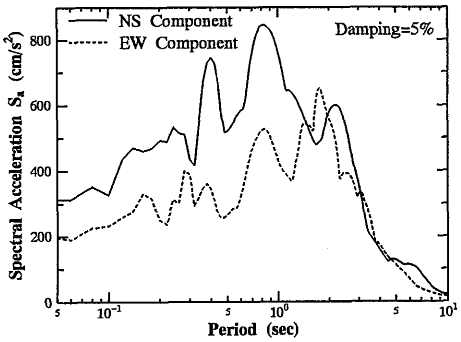


FIG. 9 Response spectra of recorded motion

The largest peak of the response spectra of the EW component in Fig. 9 is seen to occur at around 1.7 seconds, and there is a distinct peak around 2.0 seconds in case of the NS component as well. Considering that the ground period is likely to elongate during strong shaking (Karkee et al, 1993), the peaks appearing around 1.7 to 2.0 seconds in the response spectra in Fig. 9 may correspond to the fundamental ground period during strong shaking. Further investigation would be needed to confirm this.

5.2 *Dynamic Deformation Test*

The dynamic deformation tests were conducted to evaluate the strain dependence of the shear modulus

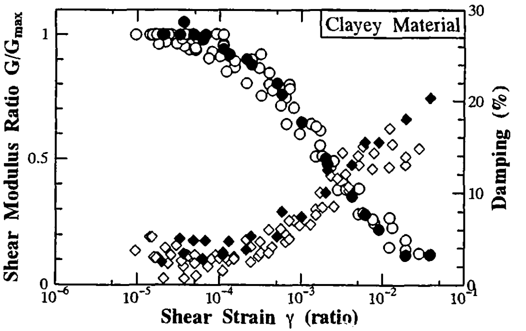


FIG. 10 Shear modulus and damping for clay

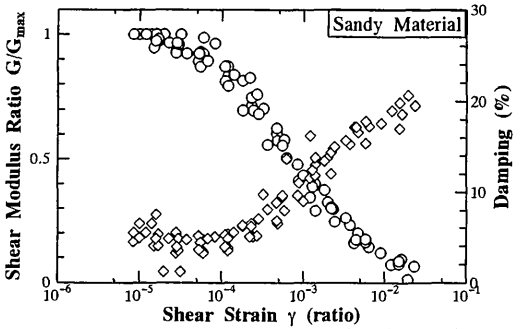


FIG. 11 Shear modulus and damping for sand

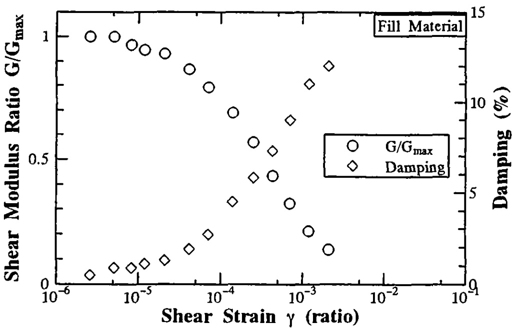


FIG. 12 Shear modulus and damping for fill material

and the damping coefficient of the different soil layers. The shear modulus G normalized by the initial shear modulus Gmax were plotted with respect to the shear strain. Such plots for clayey, sandy and fill material are given in Figs. 10, 11 and 12 respectively. It can be seen that the normalized shear modulus for clay and sandy materials tend to follow a unique pattern, that can be easily represented by a single characteristic model for the purpose of nonlinear dynamic analysis. In comparison, there is some scatter in the damping coefficient, indicating the need for caution when modeling the damping characteristics.

6. LIQUEFACTION POTENTIAL EVALUATION

The fill material at the site is well graded with fines content of 10 to 30%, sand content of 40 to 50% and gravel content of 30 to 50%. With the S-wave velocity in the range of 330 to 450m/s, the material may be considered resistant to liquefaction under normal circumstances. Evaluation for liquefaction potential was carried out as per the Japanese practice considering a magnitude 7.5 earthquake and a 200cm/s peak acceleration. The practice is based on the method of Tokimatsu and Yoshimi (1983). It was concluded that there was no danger of large scale liquefaction. The extent of liquefaction at the project area during the Hyogoken-Nambu earthquake was only minor, although there was extensive damage to quay walls presumably due to lateral spreading due to liquefaction.

7. CONCLUDING REMARKS

Site characterization efforts for the city core development project in Rokko island consisted of extensive site investigations lasting over a period of four years. Hyogoken-Nambu earthquake provided a test for the validity of the findings and evaluations based on these detailed investigations. The experience gained from the project is considered valuable for site characterization in similar situations elsewhere.

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