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Masaru Fujimoto
Penta-Ocean Construction Co., Ltd., Osaka, Japan

Takechiho Tabata
Kansai International Airport, Land Development Co., Ltd., Japan

Tsuyoshi Emura
Kansai International Airport, Land Development Co., Ltd., Japan

Masato Nakamichi
Ministry of Land, Infrastructure and Transport, Japan

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CONSTRUCTION OF MASS CONCRETE STRUCTURE UTILIZING GROUND SETTLEMENT FROM UNDERPASS CONSTRUCTION IN THE 2ND PHASE KANSAI INTERNATIONAL AIRPORT PROJECT

Masaru Fujimoto
Penta-Ocean Construction Co., Ltd., Osaka, Japan

Takechiho Tabata
Kansai International Airport Land Development Co., Ltd.,

Tsuyoshi Emura
Construction Office, Kansai International Airport Co., Ltd.,

Masato Nakamichi
Ministry of Land, Infrastructure and Transport Japan

ABSTRACT

The man-made island of Kansai International Airport is located 5 km offshore in Osaka bay and the water depth at the point is about 20 m. Thickness of the sediments beneath the island is several hundred meters, including 20 m of very soft Holocene clay layer. Huge amount of soil had been reclaimed layer over layer and the total thickness is up to 34 to 45 m. Therefore, large amount of settlement is inevitable and the average settlement forecast in the 2nd phase island over the 60 years period from the start of reclamation work is 18 m. In this paper, design and construction of 2nd phase underpass structure is discussed. The overview of construction of the airport island and settlement prediction is described first, then the idea of constructing the under water level structure while it was still above water level is introduced. The design concept of following the large displacement and method of displacement prediction is described next and verification with survey and evaluation is concluded at last.

INTRODUCTION

Kansai International Airport was built on a man made island 5 km offshore from Senshu coast, Osaka. There were several plans oversea to construct an airport on the ocean to avoid noise problem, but Kansai Airport was the first achievement. Awarded a “Monuments of the Millennium” prize from the ASCE (American Society of Civil Engineers), its land development technology and enormous challenge against the large settlement became well known worldwide. Later, construction of 2nd phase island started even offshore from 1st phase island, where the water depth is 19.5 m and the soft Holocene clay layer beneath the seabed is 21 to 26 m. The 2nd phase island is expected to undergo 18 m of seabed settlement over the 60-year period from the start of construction work. Considerable amount of 6 m is expected to continue to subside even after opening of the service. Fig.3 shows the overview image of seabed properties under the airport islands. The image of construction procedure is shown in Fig. 2. The reclamation material is mountain soil, 95 % of which is sand gravel. Reclaimed soil is over 40 m thick and the load is more than 500 kPa. Ground improvement method was applied to promote the consolidation settlement in early stage, but it was only possible to improve above Pleistocene layer. Large amount of continuing settlement was thus inevitable even after the opening of service. The elevation was designed considering the residual settlement.

Fig. 1. Osaka bay and Kansai International Airport

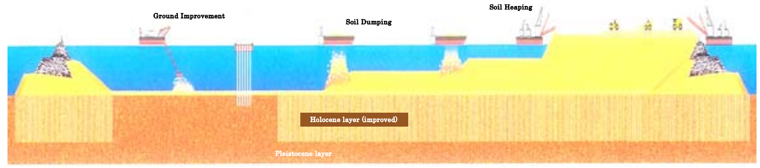

Fig. 2. Image of Construction Methods

History of Osaka Bay Seabed

Osaka Bay has elliptic shape which long axis is North East – South West direction and is about 60 km long. The water depth is less than 20 m in the East side and gradually getting shallower as getting closer to the end. Water depth in the West side is between 30 and 70 m and shows a steep increase of water depth near the East edge of Awajishima Island. Some reports point out that there may be an unknown fault there.

The thick subsurface sediments in Osaka bay has deposited throughout Quaternary. The Quaternary Osaka sediments are composed of Osaka Group, Pleistocene layer and Holocene layer. The Osaka Group (from about 1.25m years ago) is characterized by alternating sequences of marine and non-marine strata due to climatic changes. The intercalated marine clays among them were labeled as Ma0 to Ma12 in ascending order. Dating analysis was carried out by component analysis of volcanic ash layers, as well as micropaleontological analysis.

Osaka sedimentary basin came out to have 500 m thick sediments which have accumulated for the last million years and it became possible to estimate the relative speed of subsiding at basin and protuberance at hills.

According to historical geology, the coastline of Osaka Bay had changed radically since the last glacial period. During Würm glaciations', sea level was 120 to 150 m lower than present level. There was no water in the area where there is Osaka Bay today and the area was a wide plain with the old Osaka River running through.

The area around Kansai International Airport is about 4 km times 4 km and the soil profiles vary even in this area. The depth and the thickness of each clay and sand layer were checked with exploratory boring. The overview of sediments distribution is shown in Fig. 3. A deep boring survey carried out lately in 2nd phase island showed that the base rock lays 1330 m below sea level.

Settlement Prediction of Airport Island

Simulation program for settlement prediction of the airport island was based on DB (database) model, together with nonlinear model. DB model, which is a constitutive model, was developed from the results of various laboratory tests and observation of ground behavior at the 1st phase airport island in terms of such factors as settlement and pore water pressure. Flowchart of settlement prediction using the DB model is shown in Fig. 4.

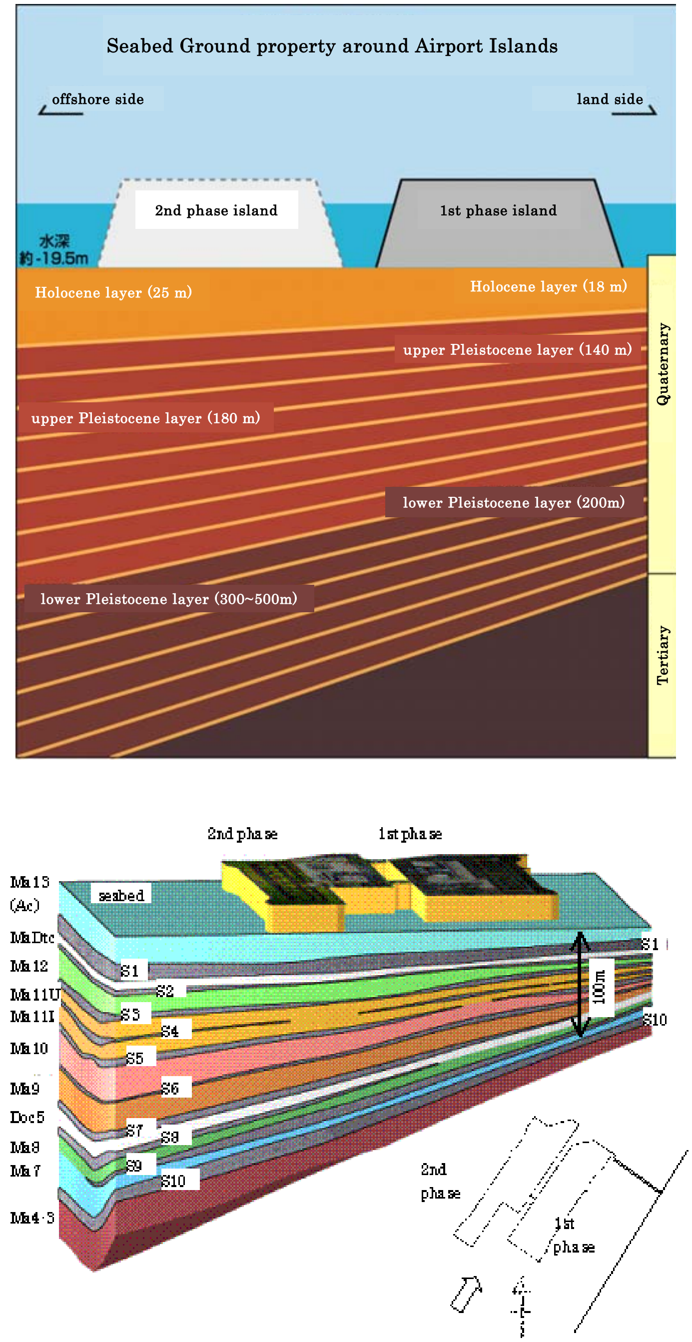

Fig. 3. General overview of ground property under airport islands

In nonlinear model, consolidation of clay layer and diosmosis in sand layer are interlocked in calculation of water pressure in sand layer. Clay is dealt with as vertical one-dimensional consolidation element, while sand as two-dimensional diosmosis element. Clay is assumed as visco-elasto-plastic model to reflect the characteristics of secondary consolidation truly. Fig. 5 shows an example of calculated settlement model compared with observed value.

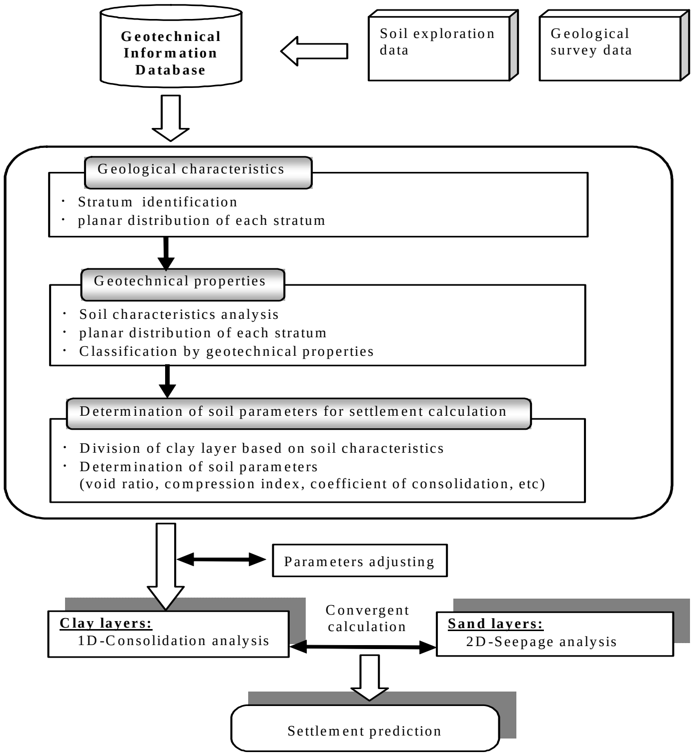

Fig. 4. Flow chart of Settlement prediction with DB model

An example of comparison of calculated settlement in respective model with observed value at a point called B-3 is shown in Fig. 5. Fig. 6 shows calculated settlement with DB model at July 2007 as a contour map, together with observed values at the same time. In Fig. 7, calculated and observed values in each stage of construction are plotted to show the correlation.

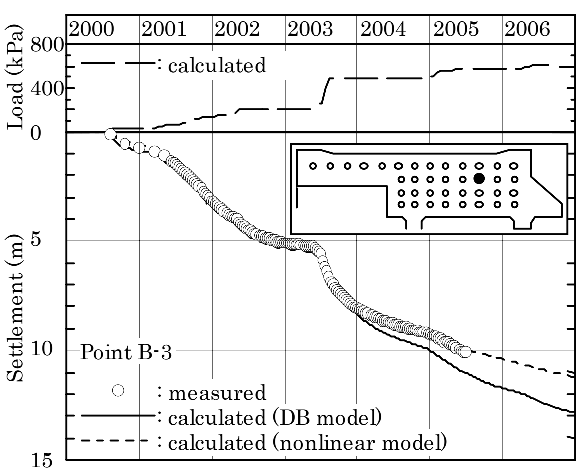

Fig. 5. Comparison of calculated and observed settlement

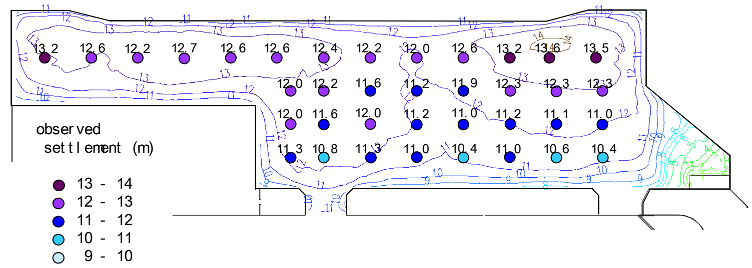

Fig. 6. Contour map of predicted settlement until July 2007, with observed value

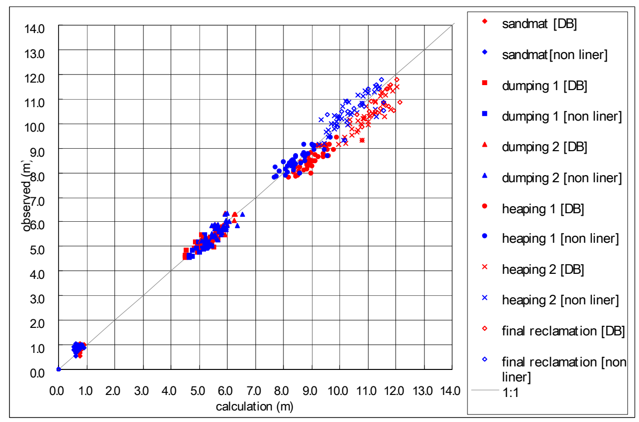

Fig. 7. Correlation of calculated and observed value in each stage of construction

UNDERPASS STRUCTURE IN KANSAI AIRPORT

The new runway is connected with existing passenger terminal, apron and runway by access taxiways. The underpass was constructed employing a multilevel intersection for access taxiways, trunk roads and GSE (Ground Service Equipment) passageways in order to ensure safe and smooth airport traffic.

Due to the difference in the time period for the development of the 1st and 2nd phase islands, there was a large difference in the amount of remaining settlement. The height in the 2nd phase side must be hence higher when the service starts, but the maximum gradient of taxi way is limited by ICAO regulation. Elevation of access taxiway at the time of construction of the underpass and the time of airport examination is shown in Fig. 8.

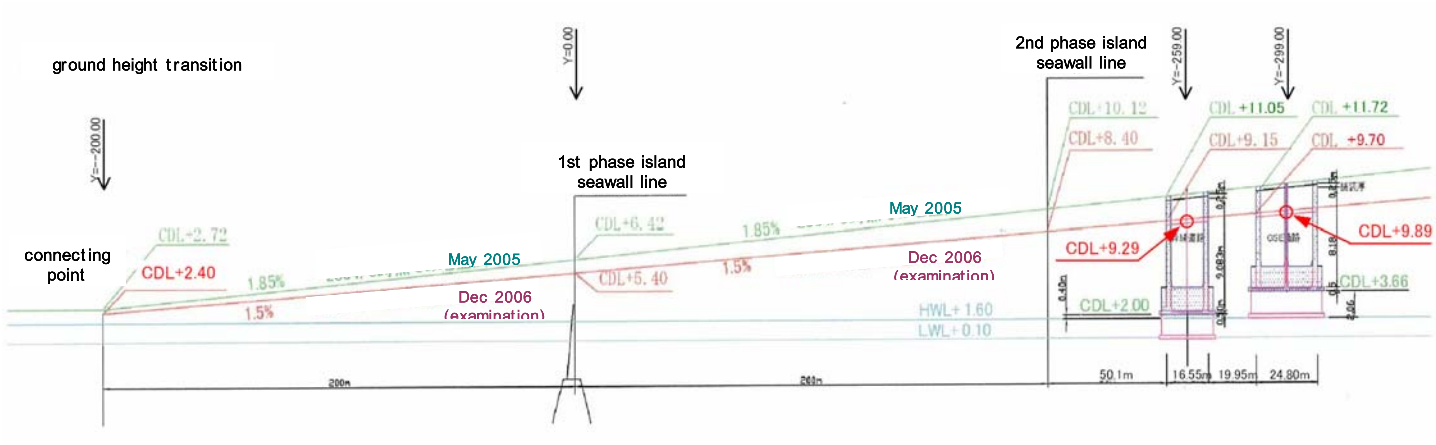

Fig. 8.Elevation Plan for Access Taxiway Connecting 1st and 2nd phase Airport Islands

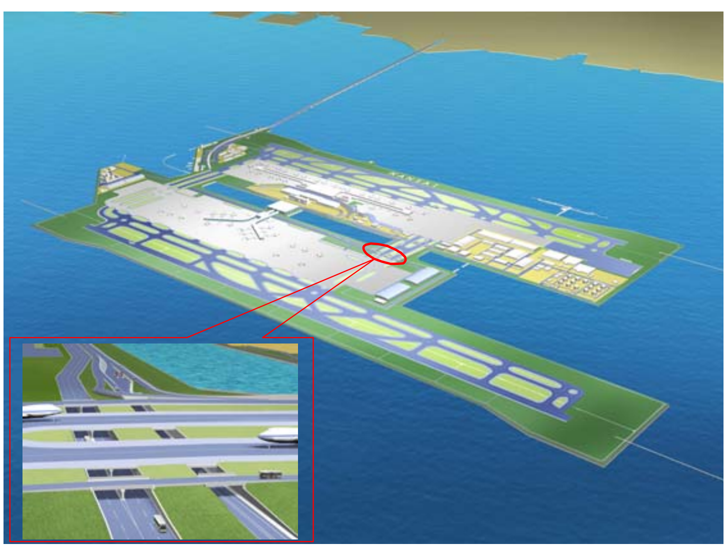

Fig. 9. Completive image of Underpass structure in Kansai Airport and its location

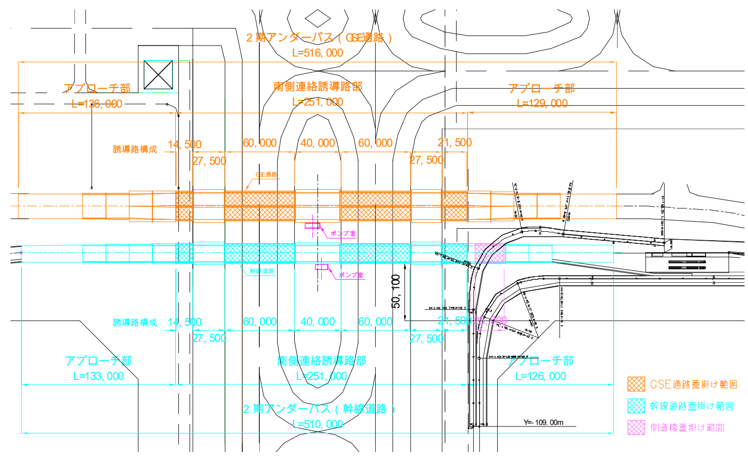

Fig. 10. Ground plan for the Underpass Structure

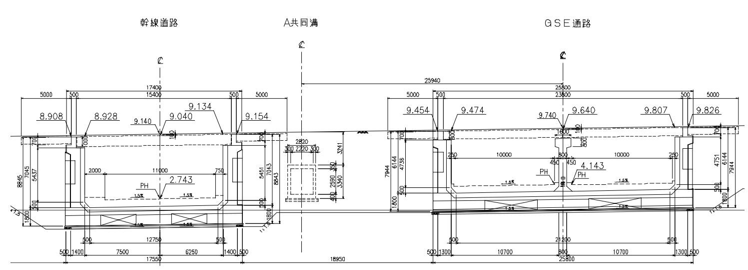

Fig. 11. Cross section of Underpass structure

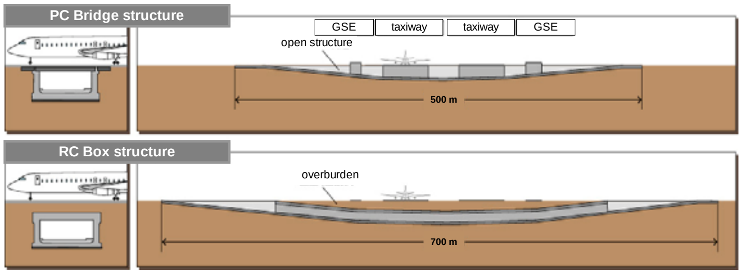

Fig. 12. Dimension comparison of PC Bridge and RC Box structure

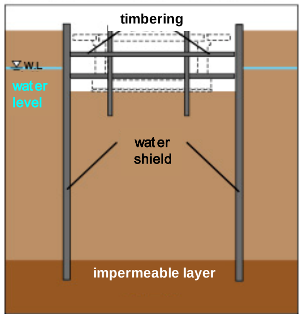

Fig. 14. Image of conventional method with water shield

In Japan, box culvert tunnel was common for underpass structure. To support big aircraft weight, thick overburden was necessary. On the other hand, PC bridge structure, which was employed in Kansai Airport, doesn't require overburden and the structure thickness is thinner. With this type, it was also possible to construct the structure above water level.

CONSTRUCTION METHOD USING SETTLEMENT

Underground structure in reclaimed land was usually constructed after the ground became stable. If we took this approach to construct the underpass, large scale of excavation and cut-off wall work was necessary. To avoid them and save cost, reclamation in this area was suspended when the required height for underpass structure was achieved and resumed after the structure was completed. That is, building the structure without water prevention and letting it settle afterwards. About 50 cm more settlement was achieved by resuming the reclamation. Fig. 15 shows the prediction of elevation and settlement of reclaimed area around the structure.

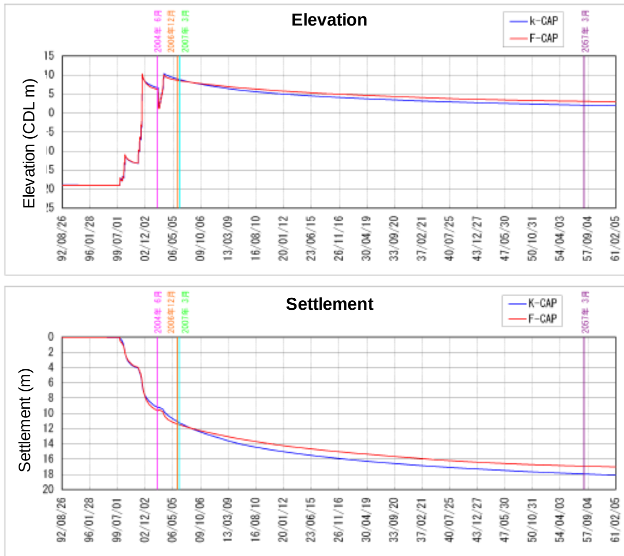

Fig. 15. Elevation and Settlement prediction of reclaimed area

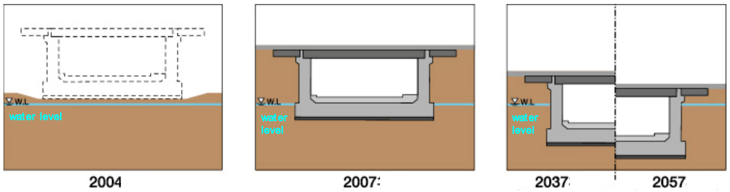

Fig. 13. Idea of using settlement for above water construction

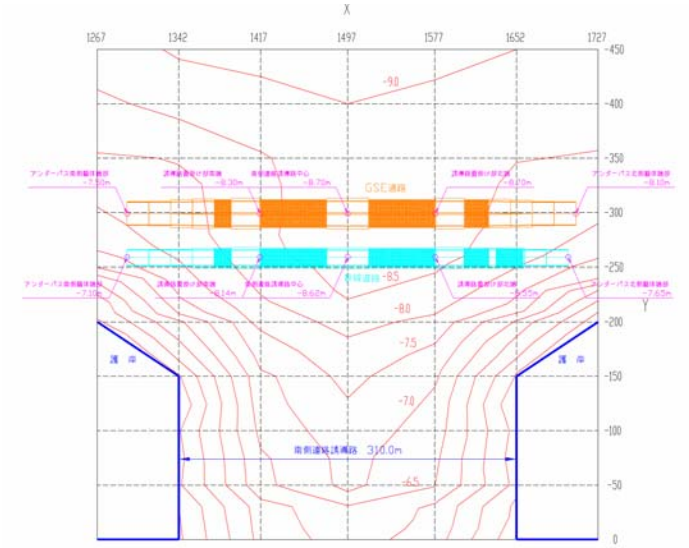

Fig. 16. Contour map of remaining settlement

GROUND DISPLASEMENT PREDICTION

Fig. 16 shows the contour map of remaining settlement until 50 years after starting service around the area near the underpass structure. Due to this un-equal settlement, it was clear that the structure will be exposed to deformation and displacement.

The question was how to predict the ground movement accurately and how to design a structure that can bear a big displacement. The elements of ground displacement took into consideration in design were 1. total vertical settlement, 2. vertical differential settlement, 3. horizontal displacement and 4. axial expansion and contraction. It was necessary to predict leaning, bending, twisting, waving and contraction of the structure, as well as the internal stress caused by these displacement elements.

1. Total Vertical Settlement. Calculated value with one dimensional FEM consolidation model was applied. In this model, seabed ground property, reclaimed thickness and construction history in each point was all took into consideration.

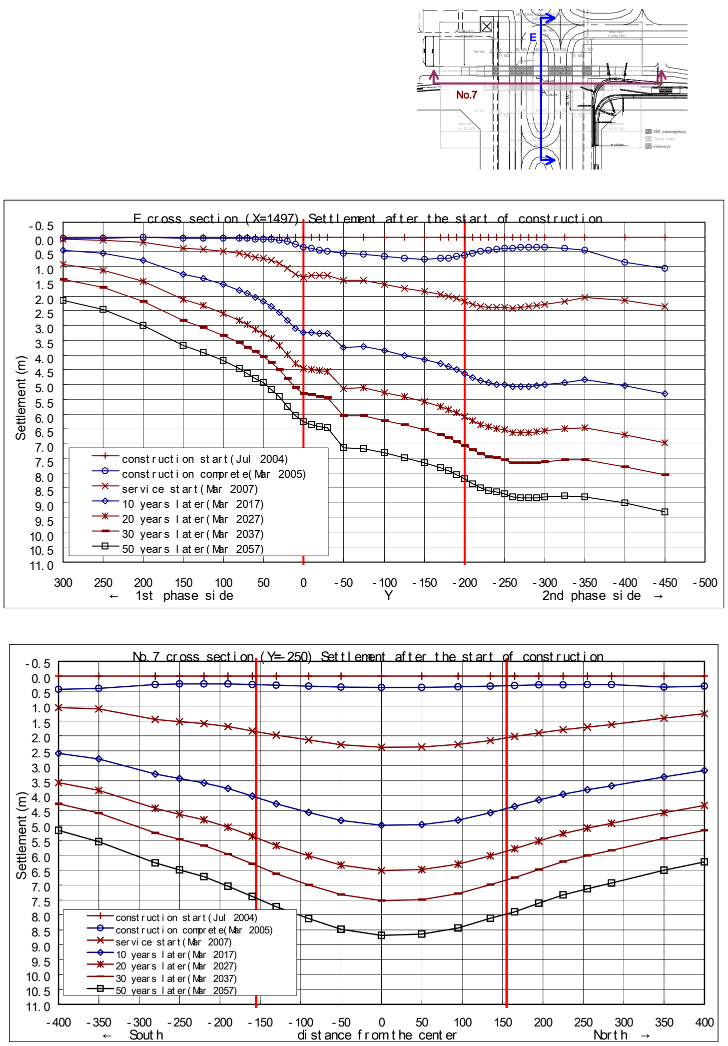

Fig. 17. Settlement Predictions in Cross sections

2. Vertical Differential Settlement. Together with the calculated value described above, the un-equal settlement ratio gathered from statistical analyses of 1st phase survey data was applied as interpolation.

The un-equal settlement would influence the grading of the structure, as well as the internal stress caused by local settlement. Structural analyses were carried on with this estimated un-equal settlement as input load.

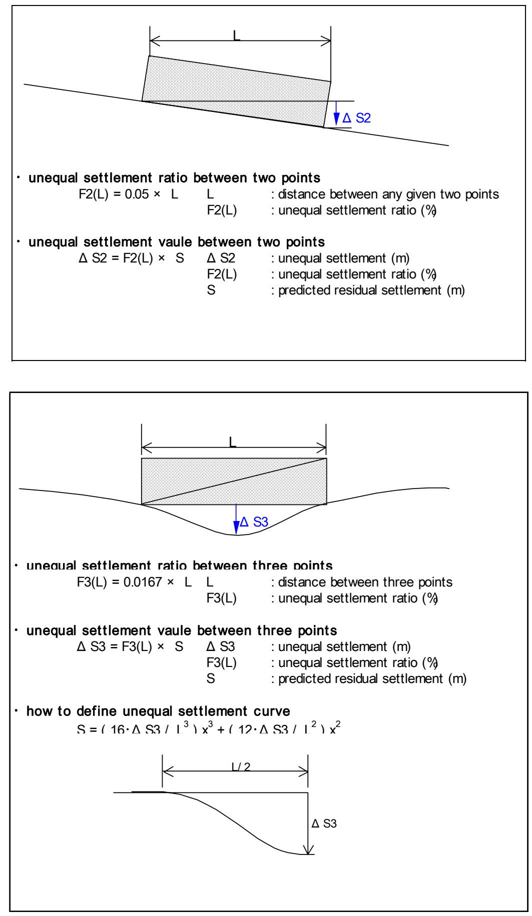

Fig. 18. Unequal settlement calculation

3. Horizontal Displacement. Horizontal displacement was calculated with two dimensional FEM model using the vertical settlement. The method is described later.

4. Axial Expansion and Contraction. The same method as horizontal displacement was used for axial expansion and contraction.

PREDICTION OF HORIZONTAL DISPLACEMENT

Fig.19 shows an example of vertical distribution of horizontal displacement measured in the 1st phase island. There was little horizontal displacement under 45 m deep and Holocene clay and reclaimed material moved in a mode as rotating around surface of Pleistocene layer.
Considering that survey, practical horizontal displacement prediction was decided to carried on with elastic FEM analyses on Holocene clay layer and reclaimed material as objects. The basic idea of this method is shown in Fig. 20.

To verify the adequacy of this method, horizontal displacement in some points near seawall of 1st phase island, where both vertical and horizontal displacement was measured, were calculated with settlement data and this method. Then the result was compared with the measured horizontal displacement. As shown in Fig. 21, it was confirmed that the calculated value with this method basically accord with measured value.

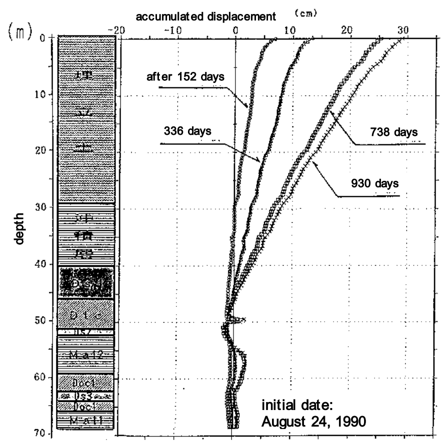

Fig.19. Vertical distribution of Horizontal displacement in 1st phase island seawall

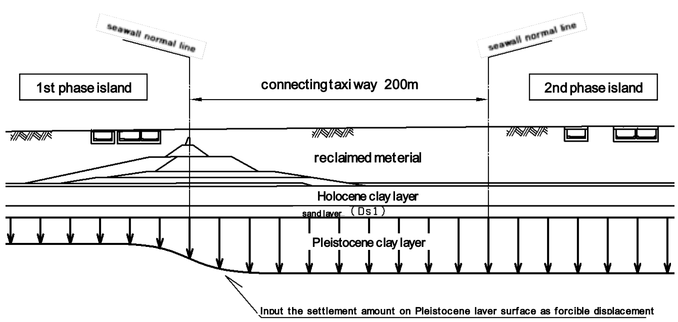

Fig. 20. Overview of Practical horizontal displacement prediction

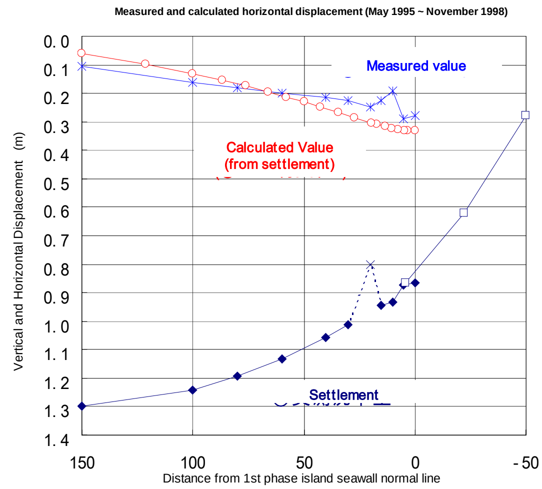

Fig. 21. Verification of displacement prediction method

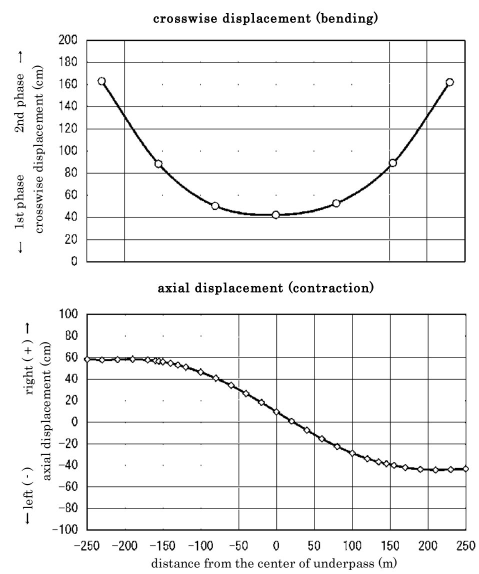

Fig. 22. Horizontal displacement in crosswise and longitudinal directions

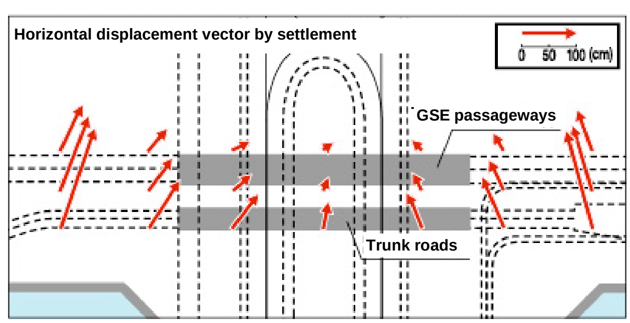

Fig. 23. Horizontal displacement vector

Fig. 23 shows the predicted horizontal displacement around the underpass structure in vector. Lateral displacement towards inland of 2nd phase island exceeded, and the amount was greater in both ends of the structure. The difference in lateral displacement between central part and both ends were about 1.2 m. There was also an axial contraction and the amount was about 1 m.

These horizontal displacement, as well as vertical settlement, was taken into consideration when designing the body and the joint of the underpass.

CONCLUSION OF UNDERPASS DISPLACEMNET PREDICTION

The settlement is calculated for each layer and the total settlement is shown as the summation of them. The calculation of the settlement depends on the load, timing and seabed property. Time - settlement curve for each layer is calculated respectively.

The area around the underpass structure was estimated to settle about 2 m during construction, and additional 6 m in the next 50 years. Due to the horizontal displacement caused by the settlement difference, the span was estimated to shrink 48 cm in GSE passageway and 99cm in trunk road. Also the structure was to be arched and both ends displace 75 cm to 135 cm west from the central part. The clearance in each joint was designed considering axial contraction, inclining and rotation of blocks and block contraction during earthquake. Central 7 - 8 joint and 8 – 9 joint were decided to save 40 cm of clearance.

Distance between two lanes of taxiway had to be 100.00 m at the time of airport examination. It was made to be 100.20 m at the start of construction, and predicted to be 99.758 m after 50 years.

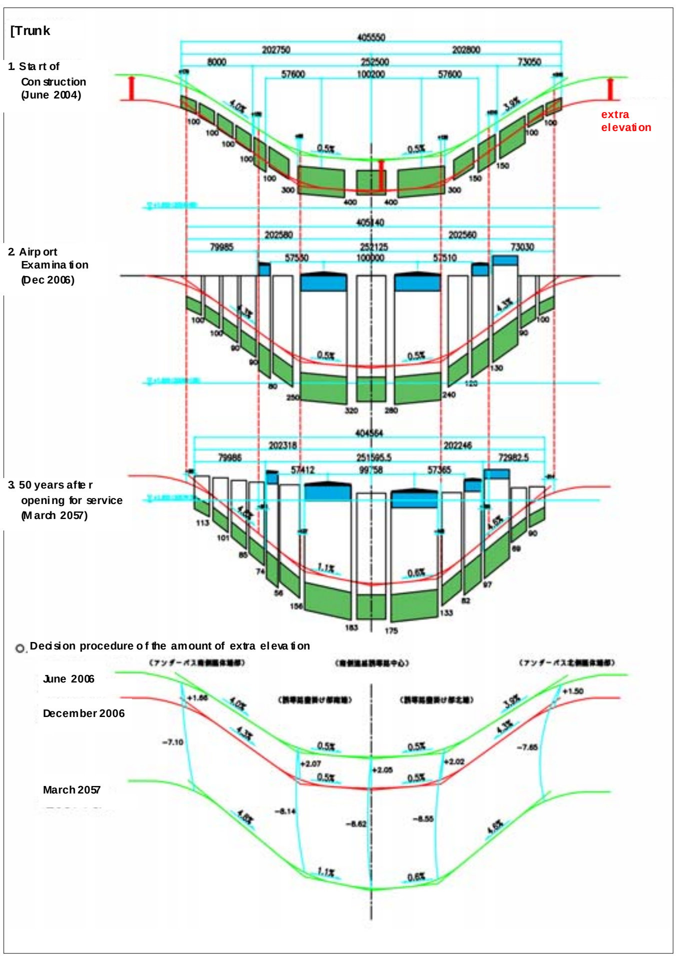

Fig. 24. Settlement and axial contraction prediction at times of construction start, complete and after 50 years in service

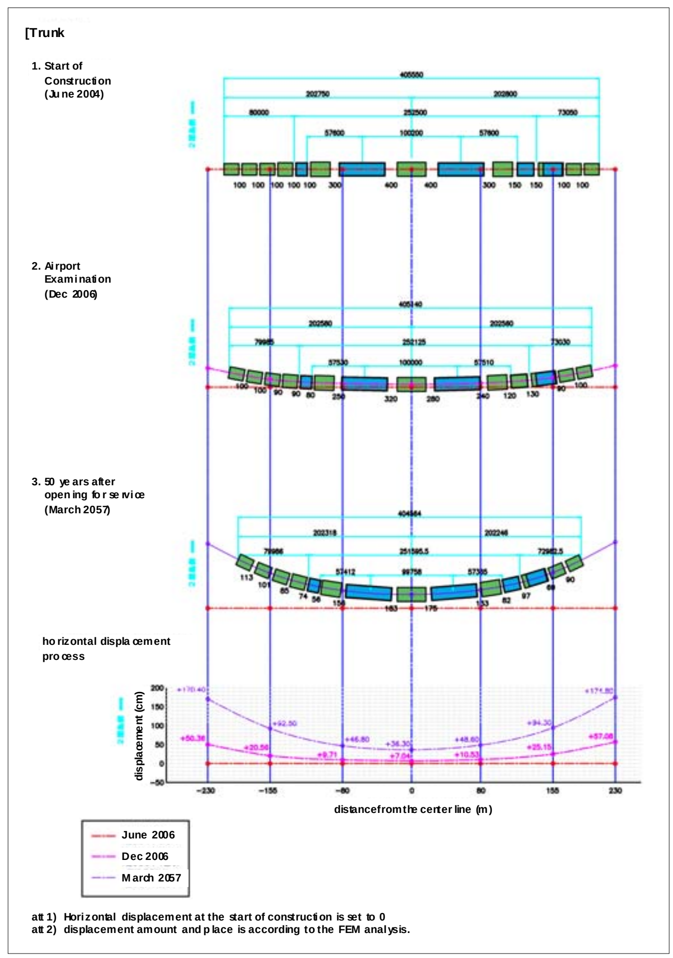

Fig. 25. Horizontal displacement prediction at times of construction start, complete and after 50 years in service

DESIGN OF UNDERPASS STRUCTURE WHICH CAN BEAR GROUND MOVEMENT

The biggest problem in the settlement was that the base of this long span structure doesn't settle evenly. To make it easier to follow the uneven ground movement, the structure was divided into multiple blocks. Certain clearance was left in between each block so that blocks don't collide with each other after uneven settlement or on earthquakes. Water sealing flexible rubber joints and shear keys to limit the perpendicular displacement between blocks were installed into each joint.

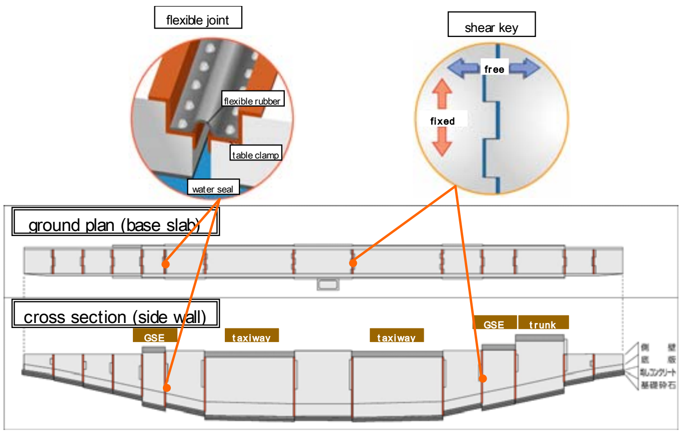

Fig. 26. Flexible joint and Shear key

The position and height of each element at the time of construction was decided so that the structure will fit into designed position and height when it is open for service.

Fig. 27. Underpass under construction

CONSTRUCTION AND OBSERVATION OF THE UNDERPASS

<u>Deciding the Amount of Extra Elevation</u>

The elevation to set the structure was decided according to the amount of settlement during the period from the placement of leveling concrete till the opening of service. The amount of extra elevation was 1.4 m to 2.0 m. The area of the underpass was about 18,000 m^2 and it took three weeks to finish the leveling concrete. On the other hand, the surface of the 2nd phase island settled 1 to 2 mm everyday and the elevation was different even during the leveling concrete work. So the extra elevation was calculated each day. After finishing the leveling concrete, the construction was managed according to designed thickness. The construction of last 1 m of sidewall was suspended until the landfill around the structure was done to wait for the settlement. If the observed settlement was different from the prediction, the final thickness was adjusted.

<u>Settlement Plate and Measurement Results</u>

Surface type settlement plates were set around the underpass structure to measure ground movement. Those settlement plates, together with measuring points on the structure, were measured with leveling. Leveling was carried on once a week before the leveling concrete was laid, and twice a month after that. There are 400 measuring points, both on and around the structure. Fig. 28 shows the measuring points. The measured value were compared with calculation on each stage of construction and the accuracy of prediction was checked. An example is shown in Fig. 29. Measured value and calculation have basically good match.

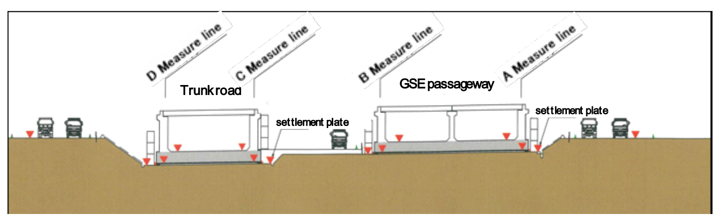

Fig. 28. Settlement and Displacement Observation points

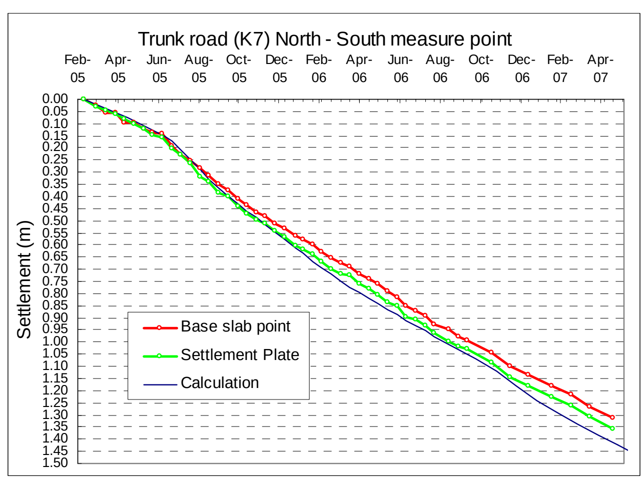

Fig. 29.Calculation - Measurement comparison

Movement of the Underpass (Observation Results)

In 26 months of measuring, the settlement of the underpass structure is smaller than prediction in most parts. The error range in average in each block is from –7% to +10%.

After constructing open culverts with base slab and side wall leaving the top 1 m, the area round the structure was reclaimed. While waiting for more settlement, clacks were found in the middle part of base slab, parallel to the axis. It turned out to be caused by the difference in elastic compression of the ground under the base slab, with the load of the fill. The movement was carefully observed and loading tests were carried out twice using heavy dump truck. The safety of the structure was confirmed. This method of suspending the final part to check the settlement prediction made it possible to correct the error in the prediction.

Fig. 30 shows the torsion movement of the underpass structure. Torsion is described as the difference in transversal settlement difference. GSE passageway tends to rotate towards East as predicted, while trunk road tends to settle almost on a level. The amount of the torsion is within allowance limit.

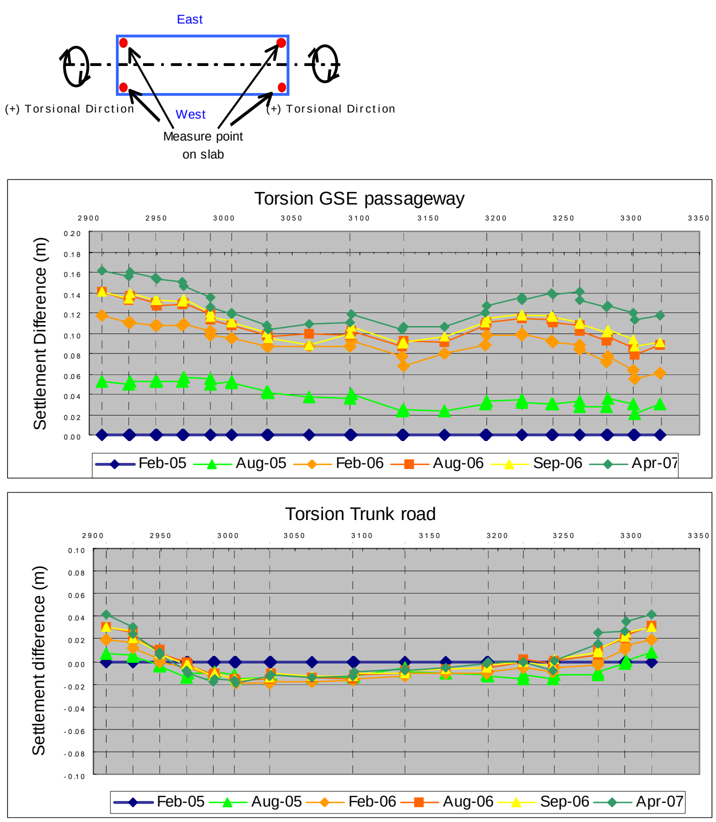

Fig. 30. Torsion of GSE passageway and Trunk road

Horizontal displacement of the underpass structure is shown in Fig. 31. Tendency of the movement towards the direction where the vertical settlement was bigger could be seen.

Crosswise horizontal displacement difference in center and both ends that causes bending movement was about 6 cm at trunk road and 7 cm at GSE passageway. Longitudinal contraction was 3 cm at trunk road and 8 cm at GSE passageway. The behavior has the same tendency as prediction, but the amount was much smaller.

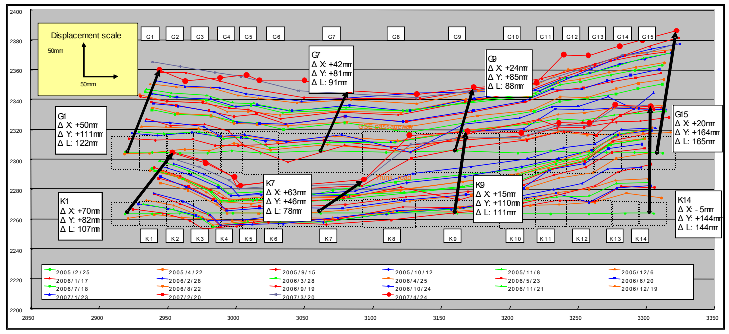

Fig. 31. Horizontal displacement of Underpass

CONCLUSION

When constructing a large structure on a reclaimed land, it is usually better to start the construction after the settlement completes and the ground get stabilized. But in Kansai International Airport, the settlement continues long time even after reclamation work is done. Waiting for the settlement to complete would be quite wasteful and the project won't be feasible. While uneven settlement and displacement of the ground is inevitable, it may be better to predict those behaviors and make the structure flexible to follow. That was the basic idea of designing the underpass structure. Precise prediction for settlement and horizontal displacement made it possible, as well as structural analysis for complicated deformation such as bending and torsion. Observation and back analysis during the construction was also important.

Horizontal displacement of the ground was predicted with simple FEM model and vertical settlement prediction in each point. The displacement prediction was used in the structural analysis. Uncertain factors were judged in safer side.

By continuing observation during and after construction it shows that the behavior of the ground and the structure is mostly within estimated range. The margin for unequal settlement was a little over safe. There was also something which hadn't been predicted. One was that the settlement during construction period was smaller than predicted and the substructure remained higher than the plan. The other was that the load of reclamation after completion of the structure caused clacks in the base slab. To avoid the latter, some method to prevent the compression settlement beneath the base, such as compaction or pre-loading, would have been effective.

Fig. 32. Underpass structure in use

Fig. 33. View of Kansai International Airport September 2007

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