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AIRPORT DEVELOPMENT IN JAPAN

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Japan is currently sponsoring a massive program of airport development. An enormous amount of money is involved. Several projects are truly remarkable, either by their size or their design. They perhaps have the world's most ambitious program of airport construction.

The most salient project is the New Osaka Airport, formally known as the Shin Kansai Kuko, or New Airport for the Kansai Region. This project involves building an island of about 5 square kilometers (actually 511 hectares or 1308 acres) in an average of about 18 meters or 60 feet of water, using an estimated 183 million cubic meters (250 million cubic yards) of fill obtained by leveling some sizeable hills across Osaka Bay. The official cost estimate for this first phase is now about $12 (!) billion, and the project is experiencing cost overruns already admitted to be around 50%.

This project furthermore involves about a further $12 billion for the construction of elevated expressways along the coast and from the interior, for new rail lines to the site, and for a highway and railroad bridge 3.75 kilometers (2 1/3 miles) long that connects the airport to a new commercial zone being created on fill extending about half a mile from the original shore line.

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Enormous projects are also underway at the two largest airports in Japan, both near Tokyo. The major domestic airport, Tokyo/Haneda, is being totally reconstructed on a major landfill of 700 hectares (about 1800 acres). Two new runways 3000 meters (10,000 feet) long, sandwiching two parallel terminal buildings around 900 meters (3000 feet) long, are now under construction for a possible opening in 1994. Additionally, a third runway 2500 meters (8330 feet) long is to be relocated 375 meters (1250 feet) to the South, parallel to its original site. Meanwhile, at the international airport of Tokyo/Narita, a major terminal complex, comparable in size to the United Airlines facility at Chicago/O'Hare, is scheduled for opening by 1993, while two new runways are in the initial stages of construction.

Significant airports are simultaneously being built all over the country, as part of the national policy to build airports capable of handling jet aircraft at the capitals of practically each of the country's 47 prefectures and districts. Because the terrain in many of these jurisdictions is either mountainous or intensely populated, the construction of several of these regional airports requires leveling hills and filling in valleys. The airports at Akita, Aomori, Okayama, and the prospective new airport at Hiroshima thus amount, in effect, to earth embankments 80 meters (235 feet) or more high.

Japan is moreover designing, building and paying for many new airports overseas. This is because the Japanese Government now operates the largest non-military foreign aid program in the world, and likes to invest it in transportation projects. The Japanese have thus been constructing both national gateways and regional airports throughout Indonesia, Thailand, and many other countries of South East Asia and the Pacific Islands, as well as in Africa and Latin America.

All together, the Japanese program of airport development is unparalleled in terms of budget, range of projects, or geographical scope. It deserves to be understood. It certainly provides several important lessons for civil engineering practice.

Geotechnical Engineering

From the purely technical point of view, the geotechnical aspects of the Japanese airport construction program are most interesting. The size and complexity of the land fill operations at the New Osaka and the Tokyo/Haneda airports are unique. The Japanese are also pioneering in the concept of building airports as earth dams. Consider a few examples.

New Osaka Airport: The construction of the New Osaka Airport requires about 30 meters (100 feet) of fill. The water depth is between 16 to 19 meters, and averages of about 60 feet. Then the design calls for the final level of the island to be about 4 meters or 13.5 feet above sea level, to guarantee that the airport will not be swamped by the high tides routinely associated with the typhoons that hit this coast every September. The remaining 7 to 10 meters of fill has to be placed to compensate for the settlement of the fill and especially that of the underlying marine deposits.

The original method for depositing the fill is as follows. First construct dikes around the site, then use bottom-dump barges to fill the entire site up to a depth of around minus 3 meters (that is to about a 10 foot draft) and then to build up the island above sea level. This final step is done by means of four large barges mounting enormous clamshell scoops, hoppers that feed conveyor belts, and a movable arm that directs the deposit of the fill. These large barges are anchored inside the seawalls and transfer the fill, brought by smaller barges from across the bay, to the desired height. The process of placing the final fill proceeds from one side of the airport island to the other, some 1250 meters (4170 feet) away. Naturally, once the island has arisen out of the water, there is no longer any possibility of moving the barges back, over the filled area, to place more fill over the island. This fact is now the source of fundamental construction problems.

The settlement of soils is of course difficult to predict precisely, especially when loose cohesive materials are dumped in water over marine sediments. In the event, the amount of settlement that is now occurring at the Osaka airport island is far greater than anticipated during the design.
The "official" reason given for the excessive settlement is that consolidation is taking place not only in the fill and the uppermost 20 meters (67 feet) thick deposit of soft alluvial clay, but also in the underlying 400 meters (1350 feet) of what the Japanese call "striated diluvial clay". This is a peculiarly Japanese term and, according to geotechnical colleagues with experience in Japan, is difficult to translate into American terms. In any case, somewhat surprisingly to a Bostonian who learned 30 years ago about the difficulties of dealing with a stratum of Boston Blue Clay of comparable thickness, the reports from the Kansai (Osaka) Airport Authority indicate that settlement in the underlying thicker layer was discounted.

The settlement, in whichever layer it is actually occurring, now apparently will be about 3 meters (10 feet) more than the about 7 meters (23 feet) forecast, although the amount seems hard to estimate accurately in the early stages of consolidation of this project. This presents a major problem since the design freeboard was only 4 meters to begin with, and the airport obviously cannot be allowed to slip under the waves.

An extra 17 million cubic meters (over 23 million cubic yards) of fill is now planned for the Osaka airport island. This amounts to placing an average of slightly more than 3 meters (10 feet) of fill over the entire site. Naturally, this operation would not actually raise the island by this much, both because the new fill itself must consolidate and because the extra weight will increase the already excessive settlement. It is quite conceivable that the final grade will not be the 4 meters above sea level that had been planned. Although the seawalls were built on sand drains and compaction piles so that they would not settle, they may yet have to be raised. These difficulties would lead to considerable delays and cost overruns in the best of circumstances.

For the Osaka project however, the situation is particularly awkward since the method used originally used to place the fill to "final" grade cannot be used for adding extra fill in the interior of the island. Barges by themselves can no longer do the job. Some kind of extensive system of conveyor belts or truck-pulled "pans" will be needed to deliver the extra fill from the sheltered anchorage over the 1250 by 4000 meters (3/4 miles by 2.5 miles) of the island. It
would seem that the planning and design process did not allow for the risk of extra settlement, and did not devise a construction process which could cope with it easily once it materialized.
Reconstruction of Tokyo/Haneda Airport: The centerpiece of this massive project is a land fill of 700 hectares (about 1800 acres) along the shoreline of Tokyo Bay. This area will provide the platform for two major runways, two massive passenger terminals with associated hardstands for wide-body aircraft, cargo facilities, plus over two miles of expressway, sunk below grade and the water table. It will both carry a wide variety of both significant positive loads from the dead weight of the buildings and the impact loads of the landing aircraft, and negative loads associated with the buoyancy of the tunnels carrying the expressways, the extension of the Tokyo monorail, and other access routes. Differential settlements can be expected to be a major issue.

The marine deposits underlying the area are not firm. As the Tokyo/Haneda airport lies at the mouth of the Tama River, in fact on what might be considered its delta, the soils underlying the site tend to be discouragingly loose and poorly consolidated. On a neighboring site familiar to my colleagues there have been large settlements over the last 30 years, and the possibility of earthquake-induced liquefaction in this highly seismic area has been a major concern. A Ministry of Transportation brochure about the site defines the situation neatly in its title: "Challenging an Extremely Soft Ground".

Finding fill for the site in the greater Tokyo metropolitan area, home to some 15 million people in the immediate cities of Tokyo, Yokohama and Kawasaki, with many more spread densely over the nearby plains, is certainly not easy. This is especially true since there is enormous competition for fill to create land along the shoreline, which can be sold at the notoriously astronomical prices in Tokyo.

The site of the relocation of the Tokyo/Haneda airport has thus been a waste disposal area of the Tokyo Metropolitan Government. Using waste materials for fill has been fairly standard in the Tokyo area and, indeed, around Osaka. The net effect, of course, is that nobody quite knows exactly what kind of material is where, and it is quite speculative to estimate the various amounts of settlement over the site. The result of this method of filling the site is that, as stated in "Challenging an Extremely Soft Ground":

> "... proper soil conditions are difficult to grasp due to drastic deviations in soil conditions, containing dredged sludge and earths from construction sites, causing extreme difficulty for surveying, designing and construction."

Differential settlement may not be a substantial problem for a housing or office project, whose relatively small buildings can be separated from each other. But differential settlement is clearly an important issue for runways, for integrated buildings 900 meters (3000 feet) long, and for rapid transit lines.

The construction team for Tokyo/Haneda airport has, along with other methods to reduce the differential settlements, installed fields of what they call "paper drains", usually known in the United States as wick drains, a special version of the common vertical drains. Where they decide extra drainage is required to speed up consolidation, they drill a grid of holes and insert a wick. The patterns observed at Tokyo/Haneda had drains about 1 meter (3 feet) on center and about 10cm. (4in.) in diameter. The fields of paper drains are about an acre each, and form a patchwork over various sectors of the site. As these drains do not seem to penetrate through the marine deposit, it would appear that they mostly serve to speed up consolidation of critical areas of the fill.

The paper drains are a way to deal with a difficult problem. The larger issue is whether the problem needed to exist at all, and if there might not have been a more reliable, and perhaps less expensive way to fill in the site. The method being used is certainly very expensive in that it is taking around eight years, and involves substantial opportunity costs -- that is, implicit interest costs -- for the money, even in Japan, since the interest rates there are now around 7%. In planning for the proposed new airport at Chep Lak Kok in Hong Kong, for example, the current design team decided that it would be far less expensive to remove the worst marine sediments on top of the deep natural clays, and replace them with homogeneous rock fill. In Tokyo, more homogeneous fill might have been barged to the Tokyo/Haneda site as at Osaka, used instead of municipal wastes, and could have reduced the risks and problems of differential settlements. The higher initial costs of this alternative might have been a worthwhile investment to reduce maintenance problems and, especially, to open the facility sooner to the paying customers.

Systems Design

In looking at Japanese airports, indeed at their civil works programs in general, we must go beyond the immediate consideration of the technical elements. The quality of a complex system is not determined by its individual components alone. The question to be asked is: Do these pieces collectively constitute a cost-effective design that will perform well under the range of situations that may occur?

Overall, it seems that many Japanese public works, Japanese airports in particular, often are not especially well designed as systems. The design process for large public works in Japan seems to involve a long series of independent decisions, taken in narrow technical contexts, without much opportunity for integration across the technical elements, let alone with the needs of the prospective users. Both foreign and Japanese airlines complain, for example, that they are not consulted when terminals and airline facilities are planned. The situation is, at a first approximation, diametrically opposite to the design processes associated with the best Japanese manufacturers, who actively promote system integration and who pay close attention to their customers.

The Japanese practice of airport design in any case results in projects that are quite different from US practice, and that seem far less cost-effective. It would appear that the systems approach we have been developing over the last generation gives American civil engineers a substantial competitive advantage. A few examples, taken from many possibilities, illustrate the point.

<u>New Osaka Airport</u>: Why is this airport sited some 3 miles from the original shoreline, and in such deep water? The official answer in Japan is that this site eliminates noise problems and permits round the clock operations, without curfews. That is a fine objective, but could it have been achieved at less cost?

Looking at the system, it appears that the controlling factors on the location are the flight tracks of aircraft, taken as being straight in and out of the runway for about 15 miles. Changing this constraint, through negotiations with the air traffic controllers and the airlines, would have allowed a site much closer to shore, in shallower water, involving far less fill and much faster construction. At Boston, for example, the usual flight path for aircraft taking off toward South

Boston is to turn 90 degrees left immediately (often before they have cleared the runway) to fly over water instead of residential areas. The cost of the Osaka project might thus have been halved, especially considering that the opportunity cost, the implicit interest, on a $12 billion project runs to about $1 billion a year.

Think about the $4 billion dollar cost overruns attributed to the fact that the island is settling much more than anticipated: How is possible that the construction process did not have contingency plans for this obvious possibility? In retrospect, it appears that the designers developed their best estimate of the settlement, and then passed it over to the constructors who felt that they were not in a position either to question this judgement or to prepare contingency plans that might imply criticism of the geotechnical experts. In any case, it is quite clear that there was not a process of system design that permitted close coordination on the big issues or properly accounted for risks.

Tokyo/Narita International Airport: This is the airport through which most visitors pass on their way to Japan. It has had tremendous difficulties from everyone's point of view. The visitor sees it as crowded and inconvenient, and probably remembers the seemingly endless bus ride into Tokyo that routinely has taken anywhere from 1 1/2 to 3 hours depending on the traffic conditions. The Japanese Government has fought intense political and even physical battles with airport opponents. For about the last 15 years, and still today, it maintains several cordons of paramilitary forces around the airport and in the last year, according to the Japanese newspapers, has repeatedly marshalled around 3000 (!) policemen in riot gear to dislodge two or three activists ensconced in some bamboo tower.

From the perspective of the air transportation system, the problem is that Japanese air traffic control authorities have limited the number of aircraft operations to 34 per hour on the single 4000 meter (13350 feet) runway. Airlines would like to schedule about twice as many flights, but are not allowed to do so. Japanese living outside of Tokyo often find themselves flying to the United States or Europe via Seoul, Korea, (and thus deserting the Japanese airlines!) simply because it is too difficult or expensive to leave through Tokyo/Narita.

To deal with the lack of capacity for aircraft operations, the Narita Airport Authority is beginning to build two new runways: a 2500 meters (8350 feet) parallel runway, and a 3200 meters (10,650 feet) crosswind runway that intersects with the existing main runway. In doing so, they are executing a plan drawn up about 20 years ago, for an entirely different generation of aircraft and pattern of traffic.

The remarkable thing about the prospective new runways for Tokyo/Narita is that they will be almost totally ineffective in meeting the demand for intercontinental and other long-distance flights! The shorter runway is inadequate for these operations. The crosswind runway, which would have been needed for the smaller, less powerful aircraft of a generation ago, is essentially never required by the Boeing 747s and similar aircraft that now use the field. Also, as an intersecting runway, the crosswind runway hardly permits any additional flights when the main runway is being used. After spending over $1 billion dollars, there will be relatively little increase in the capacity for intercontinental flights! The increase in capacity will be marginal, as smaller, shorter range aircraft shift to the new short runway.

Looking at the Tokyo/Narita airport as a system, the situation is even more remarkable. The existing runway is in fact operating way below the capacity that we normally expect in the United States. Whereas airlines are limited to 34 operations/hour at Tokyo/Narita, we would expect to operate this facility at about 50 operations/hour or more. By coordinating between the airport operators, the airlines and the air traffic control centers, American practice would probably get a 50% increase in the capacity at Tokyo/Narita without any really significant cost!

The situation at Tokyo/Narita really illustrates how the design process for airports did not come to grips with either the system or its dynamics. The process of negotiating and evolving compromises with the opponents of airport noise and disruption has been stalemated. It does not seem possible for the Japanese airport operators or builders to collaborate with the air traffic controllers to achieve the kinds of system efficiencies we now take for granted in the United States. In the Japanese context, there seems to be little possibility for revising previously published designs to accommodate to the changed conditions.

What we observe in Japan is quite different from airport systems planning as we know it in the United States. In designing the new airport for Denver for example, as for other major airport projects around the country, the terminals and other facilities are planned in close coordination with the airlines. Meanwhile, the airports and airlines are continually negotiating with the US Federal Aviation Administration to adjust aircraft operating procedures both to minimize noise impacts and to increase runway capacity. Through these kind of adjustments for instance, Boston has been able to increase the capacity of its runways by about 50% over the last 15 years - while operating one of the busiest airports in the world virtually in the middle of the city. The apparent inability to do anything comparable in Japan led to the planning for the New Osaka Airport and the $12 billion price tag for the construction of only one runway (to get a sense of what this means, Denver intends to build a five runway airport for about one quarter the price).

Summary

The Japanese programs for airport construction are clearly admirable. An enormous amount of money is being spent to build some remarkable projects. One cannot help being impressed by the scale of the effort and the commitment to its execution.

On deeper examination however, it also seems that the airports in Japan are not being designed effectively from a systems point of view. The Japanese design process for airports does not appear to involve the kind of constant interplay between the airport operators, the designers, the airlines, the neighbors and other stakeholders in the political process that we now usually take for granted in the United States. Nor does it seem to facilitate the constant updating of plans, the dynamic strategic planning we now routinely carry out.

One reason for the difficulties in systems design of public works would appear to lie in the deep-seated Japanese aversion to confrontation. Another would be that, despite a tradition of close communication between members of any group (known as "nemawashi") there seems to be little negotiation between quite distinct elements of the political structure. As concerns airports in particular, there is also the fact that university teaching and research in airport engineering appears non-existent in Japan. Whatever the reasons, knowledgeable observers do not think that this situation will change soon.

Meanwhile, it would appear that the US practice of systems design has a distinct competitive advantage in airport design. We have developed, over the past generation, a remarkable approach to systems planning and design. We have also developed an extensive inventory of computer-based models to facilitate the analysis of large number of alternatives for a complex system. Although we may take it for granted in daily practice, this process and these tools are quite unusual by many foreign standards, certainly for the Japanese. This advantage gives American designers the opportunity to make significant contributions in Japan -- if they could participate effectively in the design and construction process for Japanese airports, but that is another story.