Chemical-Soil Stabilization for Runway Shoulder Widening at Singapore Changi Airport

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Abstract

As the demand for air transportation increases, the ability of airports to expand correspondingly to cope with this increase is severely handicapped by restrictions imposed by limited airspace, land-use and environmental constraints. The introduction of larger commercial aircraft, such as the recently revealed Airbus A380, capable of carrying larger masses, becomes a commercially viable alternative. Singapore International Airline (SIA) is the launch customer for the Super Jumbo, which is scheduled to arrive in Singapore Changi Airport in 2006. To support the operations of the Airbus A380, the runway shoulders at Singapore Changi Airport have to be widened to prevent soil erosion and Foreign Object Damage (FOD) arising from the more powerful jet blast exerted by the Airbus A380 outboard engines as well as to provide a safe area that can withstand runway excursion by aircraft. Various technical proposals were evaluated by the airport authority in searching for a method of construction that would cause minimum disruption to airport operations. The strengthening of in-situ soils with a polymer modified cementitious chemical stabilizing agent for base course construction was selected on various merits. Considerations include the high rate of construction and the recycling of in-situ material, which avoids the need for extensive earthworks and is environmentally friendly. This paper summarizes the planning and evaluation processes undertaken by the airport authority in the selection of the construction technology for the widening or runway shoulders. The technical advantages and commercial benefits of chemical-soil stabilization in the airport application are derived and discussed. The construction process and some technical results of the cold deep in-place stabilization with chemical stabilizing agent are also presented.

Keywords: *A380, Runway Shoulder Widening, Airport Operations, In-Situ Soils, Environmentally Friendly, Chemical-Soil Stabilization*

Introduction

The introduction of larger commercial aircraft is a commercially viable option as the demand for air travel increases. Airbus A380 is the largest commercial aircraft built to date, capable of carrying up to 555 passengers in 3 classes, 35% more than the B747-400, and burns 12% less fuel than its competitor. In order to support the operation of this Super Jumbo, the original 3m-wide runway shoulders in Singapore Changi Airport have to be widened by an additional 4.5m on each side to achieve overall shoulder width of 7.5m in order to (a) provide a safe area that can withstand occasional runway excursion by aircraft; (b) support ground emergency response vehicles and (c) resist jet wash and prevent Foreign Object Damage (FOD) hazard. This runway shoulder widening works have to be completed by 2006 in order that the airport can safely receive the first A380 commercial flight. Other international airports are also preparing to receive the A380 between 2006-2010 (see Fig. 1 below), many of these of which are located in the East Asian region.

Fig. 1. Airports Ready for the Airbus A380

Singapore International Airline (SIA) is the launch customer for the A380. The Super Jumbo was initially scheduled to arrive in Singapore Changi Airport in March 2006 but its inaugural flight into Singapore could now be in late 2006. The Civil Aviation Authority of Singapore (CAAS) had begun planning for upgrading of airport infrastructure, including runway shoulders widening (see Fig. 2) to prepare for handling the A380 since the late 1990s. The major upgrading works have commenced since 2004 and will be completed in the 1st half of 2006, making Singapore Changi Airport one of the first international airports to be A380-compatible.

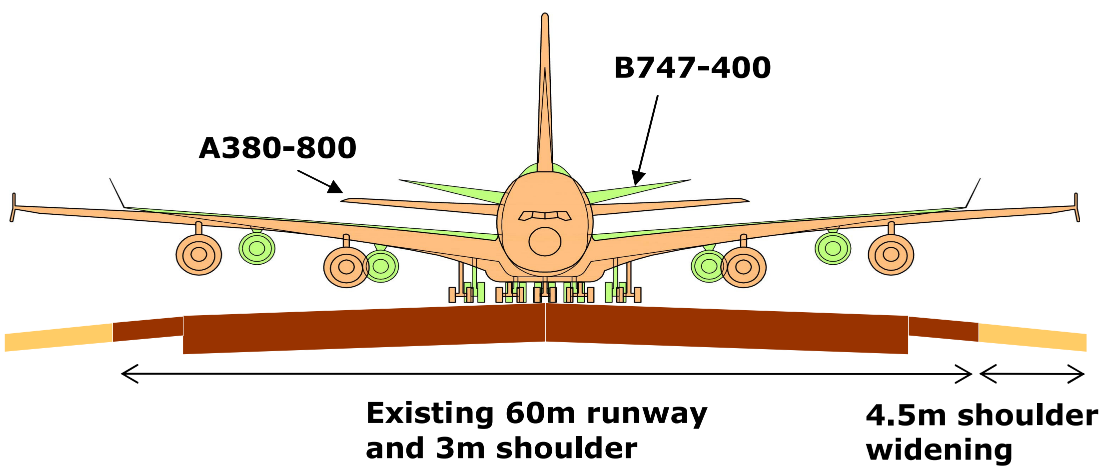

Fig. 2. Runway Shoulder Widening at Singapore Changi Airport

Annex 14 Volume I on Aerodrome Design and Operations published by the International Civil Aviation Organization (ICAO) recommends that the width of a runway shall not be less than 60m, and that runway shoulders should extend symmetrically on each side of the runway to achieve an overall width of the runway and shoulders not less than 75m for Code F aircraft (aircraft with wingspan up to but not including 80m) operations. On a 60m wide runway such as that at Changi, 7.5m wide shoulders are required to support occasional aircraft excursion and emergency vehicle access. To meet this recommendation, the existing runway shoulders have to be widened by 4.5m (reference Fig. 2 above).

Evaluation Criteria

The airport authority evaluated various technical proposals for the runway shoulder widening works to search for a technically feasible and practical method. The following criterions were taken into consideration during the evaluation process.

1) Ability to Meet Airport Operational Restrictions. Singapore Changi Airport has two parallel runways, and is one of the busiest airports in the world. Any construction works within 150m from the centerline of each runway can only be carried out with the closure of the runway concerned. To reduce the impact of the construction works to airport operations, the runway closure can only be allowed between 1:00am and 7:00am, which is during the airport's off-peak period. Actual construction time is further reduced to only about 4 hours per closure due to safety procedures (e.g. setting up of closure markers, safety briefing for workers), mobilization and de-mobilization, site clearance and cleaning before the runway is inspected and re-opened for operations at the end of each work period. The construction method should also allow the closed runway to be re-opened for operations within 30 minutes in the event of exigencies on the operational runway, with full serviceability and meeting international runway operational and safety requirements.

2) Construction Speed. The construction method should be able to achieve high rates of construction in order to shorten the total project duration, thus minimizing the period of risks and impact of inconveniences caused by construction activities and unavailability of the runway.

3) Shoulder Pavement Structural Design. The structural design should meet the general requirements of runway shoulders specified by ICAO in the Aerodrome Design Manual Part 1 – Runways (ICAO, 1984). The airport authority also specified that the design should not be less than the Type I shoulder pavement described by Airbus (Airbus, 2005). Local soil conditions should be taken into consideration and the selected method must be a proven technology with a history of applications in regions of similar climatic conditions.

4) Environmental Impact. The construction method should avoid extensive excavation and backfilling to reduce the negative impact on the environment. This not only results in lesser waste soil material to be disposed, it also greatly reduces the number of vehicular and machinery movements typically associated with excavation and hauling of materials, thus reducing harmful emissions and facilitating command and control of the works.

5) Cost Effectiveness. The project cost, which includes construction and related costs, is also one of the factors in the evaluation of the method of construction. Subsequent recurrent maintenance costs were also given significant weightage when considering the available options.

The proposed construction methods can generally be classified into two categories: replacement and non-replacement, the latter of which allows in-situ soils to be re-used as a source of construction material. Various technical proposals were evaluated thoroughly based on the criterion mentioned above, with non-replacement methods offering added advantages over conventional pavement construction (replacement method). The non-replacement method of strengthening in-situ soils with polymer modified cementitious chemical stabilizing agent for the base course, topped by asphalt concrete as a wearing course (Fig. 3) was eventually selected on various merits which will be discussed later.

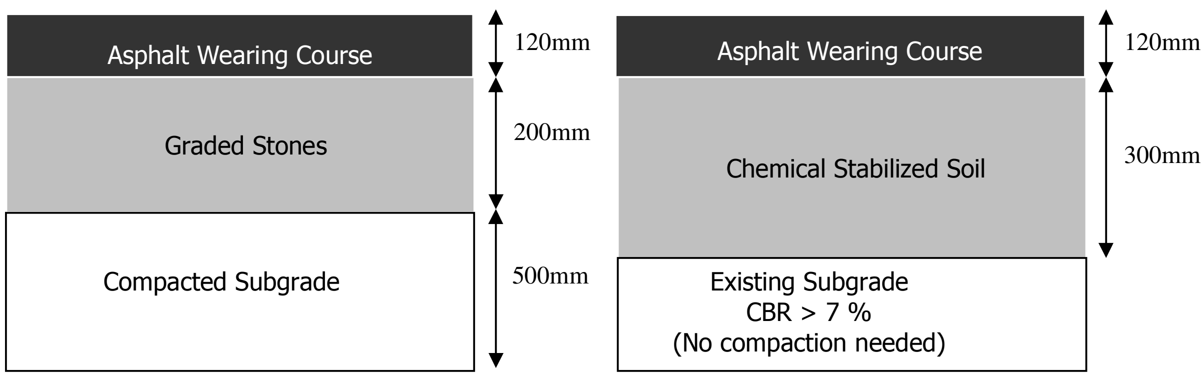

Fig. 3. Cross Section of Existing Runway Shoulders vs. Widened Section by Chemical Stabilization

<u>Chemical-Soil Stabilization</u>

Soil stabilization refers to the mixing of chemical mixtures with in-situ soils to improve the volume stability, strength and strength-strain properties, permeability and durability of the soil through chemical reaction between the chemical and soils. The stabilized soils form a semi-rigid platform, which is commonly used as the base course for various types of pavement structures (Wu & Yong, 2004). The selected chemical stabilizing agent is a polymer modified cementitious soil stabilizing agent that has been successfully used in tropical region for more than ten years with numerous project records (Suhaimi & Wu, 2003). Non-homogeneity of soils, which includes stone, beach sand, silt and clay or their mixtures, along the longitudinal profile of the runways, coupled with the limited construction time window, meant that the ideal application of using different stabilizing agents for different soil types is not practical. Therefore a special version of the stabilizing agent, which is able to treat a wide range of soils from gravel/sand to silt/clay, as well as their mixtures, was used.

The design criteria of the 300mm thick stabilized soils base course for the new runway shoulders are (a) UCS (unconfined compressive strength at 7-day) not less than 1.5 MPa; (b) CBR (California bearing ratio at 7-day) not less than 90%; and (c) M_R (resilient modulus at 28-day) not less than 3,000MPa. A minimum dosage of the chemical at 3.75% (by the dry weight of soils to be stabilized) was applied to all runway shoulder widening areas under various soil conditions.

The process of in-situ soil stabilization is straightforward and fast with three major steps: <u>Spreading</u> of the chemical over the surface of the soils to be stabilized; <u>In-situ mixing</u> of the chemical with the soil; and Compaction. Daily stabilization rates (based on 8-hour day) for new roads can average up to 1km (7m width) with a set of specialized stabilization machines and conventional road construction machinery. An initial estimate of the stabilization rate, taking into consideration site variations and contractual requirements, is 166m (4.5m width) per 6-hour runway closure.

Runway Shoulder Widening Processes

A typical runway shoulder construction schedule for a 6 hour runway closure period (from 1:00am to 7:00am) is shown in Fig. 4, of which the effective construction duration is only about 4 hours (from 2:00am to 6:00am) due to safety procedures and housekeeping requirements. Major construction activities include **Excavation** and removal of the topsoil (Photo 1); **Spreading** of the chemical agent on the surface of the soils to be stabilized (Photo 2); **Mixing** of the chemical with the in-situ soil (Photo 3); **Compaction** of the chemical-soil mixture (Photo 4); and immediately upon compaction of the stabilized layer, **Paving** of a layer of asphalt concrete (Photo 5). A second layer of asphalt concrete is laid the following closure to complete the widening. The widened runway shoulder is shown in Photo 6.

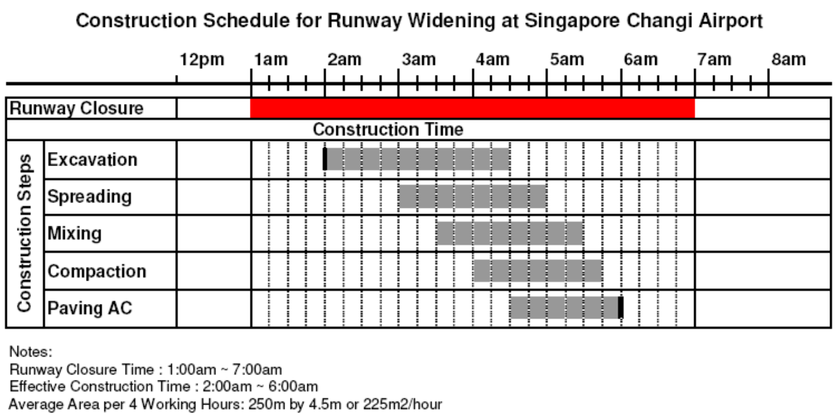

Fig. 4. Typical Construction Procedure of New Shoulders

Photo 1. Excavation

Photo 2. Spreading

Photo 3. In-Situ Mixing

Photo 4. Compaction

Photo 5. Paving Asphalt Concrete

Photo 6. Completion of Widening

The peak hourly and daily construction rates for the new shoulder pavement are about 280m²/hour (62.5m length by 4.5m width) and 1,125m²/day (250m length by 4.5m width) respectively, which is significantly faster than the initial planned daily rate of 166m length by 4.5m width. A comparison of the actual construction time versus planned timings, and average daily rates for the shoulder pavement construction by chemical-soil stabilization method is shown in Table 1.

Table 1. Comparison of Planned and Actual Construction Period for Runway Shoulders Construction using Chemical Soil Stabilisation Method

Runway	**Planned Construction Period**	**Actual Construction Period**	**Actual Working Days**	**Remarks**
I	90 days	(31/05/05~11/07/05) 42 days	31 days	Ave. 208 m/day
II	90 days	(08/03/05~29/04/05) 53 days	29 days	Ave. 226 m/day
I & II	180 days	95 days	60 days	Ave. 217 m/day (Total:13kmx4.5m)

<u>Quality Control</u>

Quality control was carried out through sample testing during and after the stabilization process to ensure that the completed runway shoulders were constructed according to contract specifications. CBR of the sub-grade were randomly checked to ensure that validity of the assumptions of in-situ CBR. In addition to quality assurance for the chemical powder, the actual chemical powder weight was sampled during the mechanical spreading process as a means to ascertain that the chemical dosage, which is dependant on spreading rate, was applied as specified (Photo 7). Immediately after the completion of in-situ mixing, specimens were collected and prepared (Photo 8), kept moist for 7 days before conducting UCS and CBR tests (Photos 9 and 10). The degree of compaction of the stabilized layer was measured using nuclear density testing devices to ensure sufficient compaction (Photo 11). Resilient modulus tests (MR) were also carried out at 28-day (Photo 12).

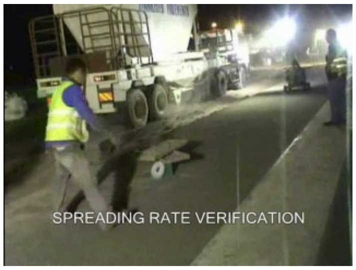

Photo 7. Spreading Rate Check

Photo 8. Preparations of Specimens

Photo 9. UCS Test

Photo 10. CBR Test

Photo 11. Nuclear Density Test

Photo 12. Resilient Modulus Test

The results of UCS and CBR laboratory tests are shown in Fig. 5. The average value of UCS is 3.0MPa and CBR is 200%. The wide range of test data, even though the same chemical dosage is applied, is a result of the variation of soils along the runway profile.

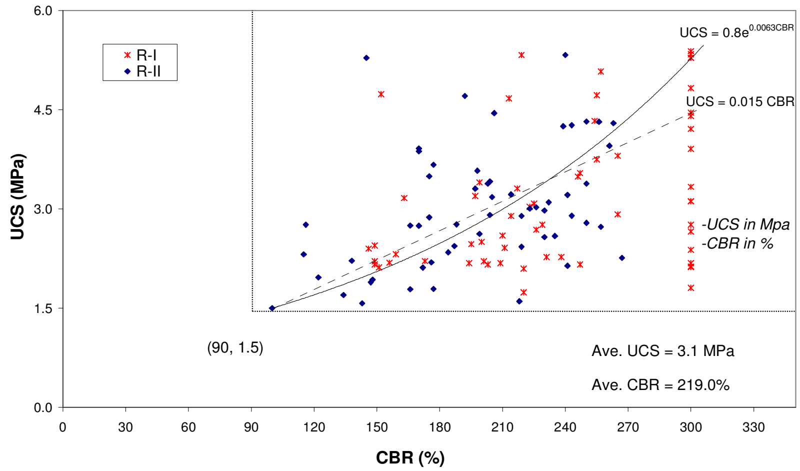

Fig. 5. UCS and CBR Testing Results

Values from resilient modulus tests were in the range of 12,000 – 15,000MPa, which exceeds the minimum requirement of 3,000MPa as specified in the contract specification, and higher than what would have been achieved if the conventional graded stone base course was used. Overall quality of the stabilized soils as the new shoulder base course, as shown by laboratory acceptance test results, is satisfactory. 3 months after the completion of shoulder widening on one of the 2 runways in Changi Airport has not revealed any defect that can be positively attributed to instability of the stabilized base.

Benefits of Chemical-Soil Stabilization in the Airport Environment

The used of in-situ soils as construction material greatly reduced the number of vehicular and machinery movements that would have been required for the hauling of construction and waste materials if conventional replacement methods were used, alleviating command and control issues within the delicate airport operating environment. Using 10ton tipper trucks, an average of 25tons of chemical were imported and 230tons of excavated topsoil exported daily for a construction area 250m long by 4.5m wide, accounting for approximately 20 trips. In comparison, 100 trips would have to be made daily for exporting 630tons of excavated soil and importing 500tons of graded stone for construction of the base course through the replacement method. If the average time for airport security clearance is 3 minutes/trip, it would take 9 hours daily for all these vehicles to enter the airport, seriously impeding work progress, not withstanding the increased exposure to security and operational safety risk.

Furthermore, actual working manpower was less than 50 workheads, with less than 20 machinery and vehicles within the runway at any one time. This avoided the communication and coordination nightmare in exigencies when the runway had to be re-opened for operations within 30 minutes. The risk of Foreign Object Debris (FOD) left on the runway was also greatly reduced.

The actual rate of runway shoulder widening by in-situ chemical-soil stabilization was faster than initially planned, allowing the shoulder construction works on the two 4,000m long runways to be completed 2½ months ahead of the 6-month schedule, despite the entire construction process being carried out under severe time and operational restrictions. On hindsight, conventional replacement methods looked unlikely to achieve more than 30% of the construction rate under similar conditions.

The recycling of in-situ soils as construction material is environmentally friendly and avoided the need to dispose up to 21,000tons of, otherwise, "waste material", which translated to a saving of nearly S$200,000 in disposal cost for the airport authority.

Based on breakdown of the contract price and actual work done, the unit cost for the widened runway shoulder pavement, inclusive of soil stabilization, paving of asphalt concrete and reinstatement works, is approximately S$70/m², 65% of which goes to soil stabilization works. Recurrent maintenance cost is assessed to be no more than that required for the maintenance of existing runway shoulders as both are paved with asphalt.

Conclusion

The runway shoulder widening works required for Singapore Changi Airport to comply with ICAO recommendations have been completed on both runways since early August 2005. Changi Airport is well on its way to become one of the 1st international airports to be fully Airbus A380-compatible.

Comprehensive project planning and methodology evaluation by the airport authority was critical in the smooth and on-time completion of the shoulder widening works.

The chemical-soil stabilization method is applicable under the restricted operating conditions in the airport environment, and effectively minimized unnecessary disruption to airport operations and any risks associated with the works. The process is environmentally friendly and expeditious. Assurance on quality of the completed works can be controlled through sample testing to specifications. Technical performance to-date is satisfactory.

Acknowledgements

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