A CASE STUDY - UPGRADE OF THE TERMINAL APRON AT MUMBAI INTERNATIONAL AIRPORT

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INTRODUCTION

Chattrapati Shivaji International Airport (CSIA) at Mumbai, India, currently handles in excess of 21 million passengers and 465,000 metric tonnes (512,500 Tons) of cargo per annum. These figures are forecast to grow to 40 million passengers and 1 million metric tonnes (1.1 million Tons) of cargo per annum by 2015.

In April 2006, Mumbai International Airport Private Limited (MIAL) signed an Operational, Management and Development Agreement with the Airports Authority of India (AAI) to operate, maintain, develop, design, construct, upgrade, modernize, finance and manage the airport for a period of 30 years, with an extension option for a further 30 years. In 2007, Larsen & Toubro Limited, ECC Division (L&T) were awarded a contract by MIAL to upgrade the airport as part of the CSIA Expansion and Renovation Program. MIAL is a joint venture company owned by a GVK Group consortium and Airports Authority of India (AAI).

As part of the CSIA Expansion and Renovation Program, the existing international terminal and the associated aprons are being replaced. The project consists of the replacement of approximately 540,000 m^2 of existing rigid pavements with over 950,000 m^2 of new pavement. The aprons will be in use throughout the 3 year construction period, and are currently operating near saturation traffic levels. Detailed staging has been implemented to achieve a balance between the operational use of the aprons and adequate work faces to achieve construction efficiency. The project timeline is further complicated by an annual monsoon period of four months duration.

The reconstructed aprons have been designed to ICAO standards utilizing FAARFIELD software for pavement design. Geometric and pavement designs were designed in accordance with ICAO Annex 14 [1] and ICAO Aerodrome Design Manual Parts 1, 2 and 3 [2, 3, 4]. FAA Advisory Circular 150/5320-6E [5] was used as a guide for pavement designs and detailing.

The forecast usage for each apron taxilane and aircraft stand was analyzed and pavement thicknesses were determined using FAARFIELD. The aircraft parking stands were designed using fewer departures but with correction factors to cater for reduced wander. Both designs gave similar results, hence a uniform pavement thickness was adopted throughout.

The majority of the new apron footprint rests over existing concrete and flexible pavements which will be used as a foundation for the new rigid pavements to economize the design and expedite construction. The apron requires vertical shape correction which leads to varying degrees of cut and fill over the existing surface. The existing apron pavement will be reused in a number of ways, including rubblization of the existing concrete pavements, recycling of other concrete pavements for use as subbase where rubblization is not feasible, and removal of the existing wearing courses and utilization of the underlying pavement courses as subbase. Where none of this is possible due to inadequate cover over subgrade, new full depth pavements have been adopted.

The subbase for the new concrete pavements is therefore a mixture of rubblized concrete, existing subbase and new subbase. Utilizing rubblised concrete as a subbase for new rigid pavements is a highlight of the project.

EXISTING & PROPOSED APRON LAYOUTS

The runways, taxiways and aprons at CSIA are currently certified for use by ICAO Code E (FAA Airplane Design Group V) aircraft, however some movement areas are being upgraded to ICAO Code F (FAA ADG VI) requirements as part of this project. CSIA currently caters for around 21 million passengers per annum and 550 aircraft movements (arrivals and departures) per day, split between a domestic terminal complex (T1) and an international terminal (T2). At the commencement of the project, the original international terminal (T2) was a convex shaped single concourse building with 14 Code E contact stands. The greater T2 apron also provided a further 15 Code D/E (ADG IV/V) and 6 Code C (ADG III) remote stands. This gave a total of 35 stands on the existing apron at the commencement of the project.

As part of the CSIA Expansion and Renovation Program, the existing T2 building and apron are being replaced with a new x-shaped integrated terminal (with 3 convex shaped faces) that will be used for both domestic and international operations. In the initial phase of development due for completion in 2013, the new apron will provide 3 Code F (ADG VI), 40 Code E (ADG V), 0 Code D (ADG IV) and 5 Code C (ADG III) stands, giving a total of 48 stands on the new apron. During the peak domestic times, 17 of the larger contact stands can be converted on a 2 for 1 basis into Code C stands. The remote aprons also can convert 11 Code E stands into 21 Code C stands. In the final phase of development a total of 38 Code E/F contact stands, 14 Code E/F remote stands and 19 Code C remote stands will be provided (total 71 stands).

The orientation of the existing and proposed terminal building faces differ significantly (by up to 90 degrees), which means that the existing apron pavements could not be retained for use with the new building due to incorrect orientation of slopes, drainage and underground services and a general level difference between the existing and proposed terminal buildings. The proposed apron covers an area of approximately 950,000 m^2 (10,225,000 ft^2).

CONSTRUCTION STAGING

The location of the new international terminal building sits directly on the site of the existing terminal building, carpark and apron. At the commencement of the project, the airport operator declared that the existing terminal and 24 wide body parking stands must remain operational throughout the duration of the project, hence the terminal and apron developments must be constructed in a series of discreet stages in order to maintain airport operations. The new pavements are planned to be completed by mid 2013. This is a difficult task given that Mumbai experiences a heavy tropical monsoon period for four months per year (June to September) which effectively halts all civil works. This leaves around 32 months to complete the pavement works, at a rate of nearly 30,000 m^2 (325,000 ft^2) per month.

Numerous temporary parking stand layouts were analyzed during the initial design phase of the project in order to determine how many of the existing parking stands could be temporarily relocated to free up space for construction of the new apron, taxiways and terminal building. An additional 3 wide body parking stands (2 contact and 1 remote) were constructed on the eastern side of the existing apron at the commencement of the project to provide some flexibility to shuffle parking stands during the works. Even with this additional capacity, a maximum of only 5 existing wide body stands could be decommissioned during the initial construction stages.

Given that limited space was available on the international apron for temporary parking of wide body aircraft, the construction staging sequencing was limited to shuffling between small areas, and commissioning / decommissioning small numbers of stands at the completion of each stage. For example, during the first half of the project, parking stands were commissioned in groups of 3, 2, 1, 4, 4, 3 and 5 at the completion of each stage.

A total of 15 construction stages have been designed for the project, as shown in Figure 1 below. Each stage required careful planning of airport operations, site access routes, safety markings & barricades as well as detailed planning of the construction sequencing and commissioning schedule to enable aeronautical charts and NOTAMs to be published well in advance of the works.

The construction staging led to optimization of aircraft taxiways and associated safety clearances in order to maximize the construction works area. Although this exercise was largely successful, some works had to be planned to be undertaken on a time limited basis within the taxiway strips. Under this procedure, men and equipment would enter the strip under supervision of works safety officers, and would vacate the works site for each wide body aircraft movement.

It should be noted that the international apron redevelopment is part of the wider CSIA Expansion and Renovation Program, which includes major widening, strengthening and shape correction of both of the airport's cross runways, realignment of the main parallel taxiway to Code F clearances, construction of over 625,000m^2 (6,725,000ft^2) of new taxiway pavement, as well as 12 km (7.5 miles) of new open drains and box culverts, a new airfield ground lighting system with over 5,000 new lights and 500km (310 miles) of cabling, and 60km (37 miles) of new AGL and electrical duct banks, all within the same time period. As a consequence, the T2 construction staging also had to be cognizant of the impact on the airport operations and works areas for the remainder of the airport.

EXISTING PAVEMENTS

The new apron area is located over varying terrain including existing flexible & rigid pavements, former building sites and grass areas. All the existing contact and remote aircraft parking stands are rigid pavements, apron taxilanes are a mix of flexible and rigid pavements, and ground service equipment storage areas are generally reduced strength flexible pavements.

Extensive geotechnical investigations were undertaken with an aim to establish the structure of all existing pavements and to determine the subgrade classification and strength across the entire apron. A total of 45 bore holes were undertaken on the existing pavements to determine the USCS materials classification and thickness of each pavement layer. Standard Penetration Tests (SPT) were conducted on the subgrade through each bore hole to determine the N values which could be correlated to provide subgrade E modulus, CBR & coefficient of subgrade reaction (k) values for pavement design purposes. As the pavements have been in place for many years, it was agreed that the subgrade was at an equilibrium state and that field subgrade reaction was a better option to laboratory derived values. A limited number of plate load tests and laboratory CBR tests were conducted to verify the correlations used to calculate CBR and k values from the field measured N values. The plate load testing was particularly limited due to operational restrictions at the airport.

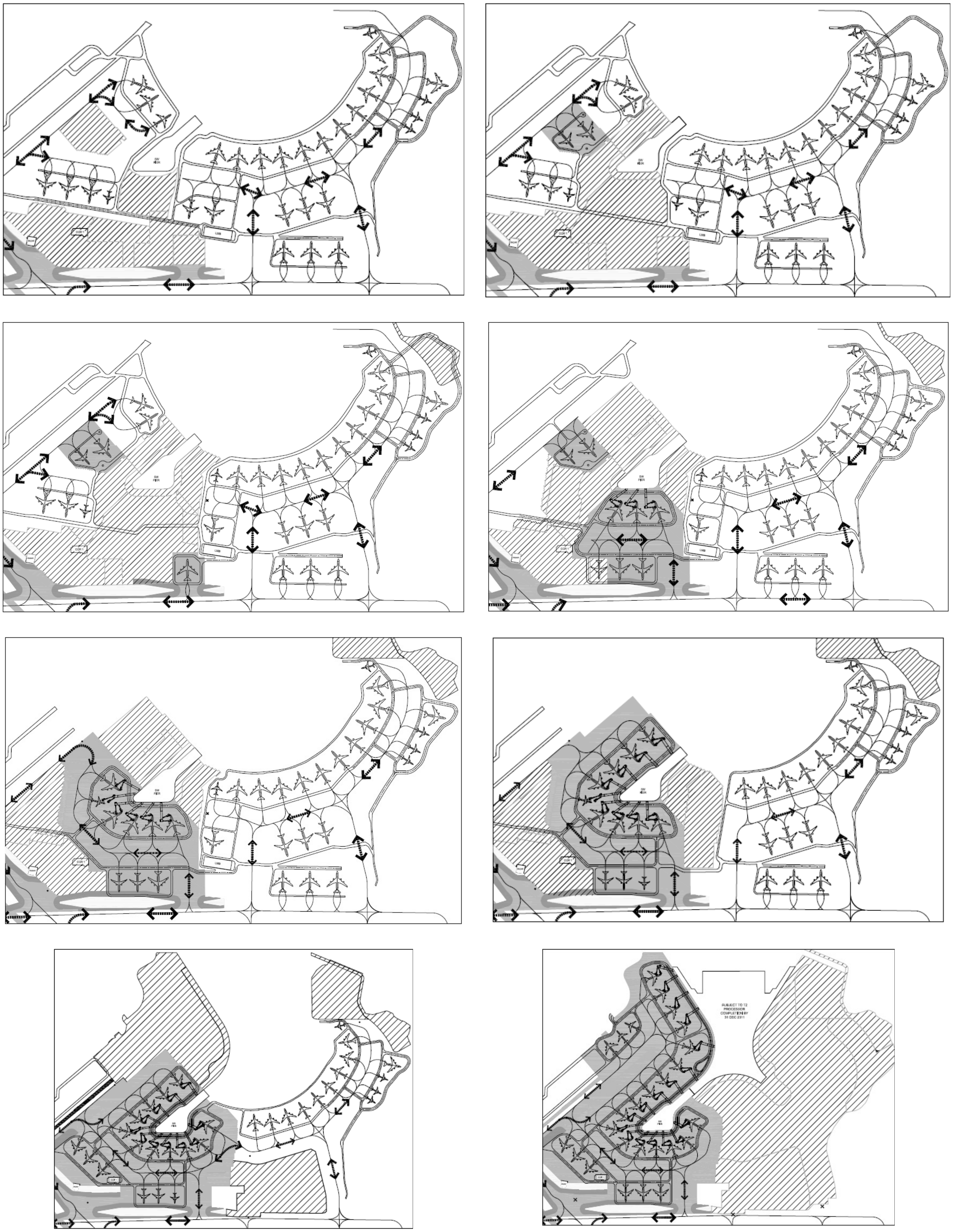

Figure 1. T2 Apron Construction Stages (Not all stages shown).

The 3 main pavements identified by the geotechnical investigation were:

- Rigid aircraft pavements
- Flexible taxilane pavements and
- Ground Support Equipment (GSE) flexible pavements

The existing rigid pavements are of various ages, ranging from 3 to 30 years. The older rigid pavements are presently in various stages of deterioration, with longitudinal and transverse cracks as well as edge spalls and corner breaks noticeable on around 30% of existing slabs. Differential settlement (faulting) is also evident across some slabs, up to 15 mm (0.5”). The existing rigid taxilane and aircraft parking stand pavements have PCC varying in thickness from 400 mm (15.75’’) to 600 mm (23.5’’) with E modulus values in range of 16,000 MPa (2,320,000 psi) to 22,000 MPa (3,190,000 psi). The E modulus values were estimated by compression testing extracted cores as per Indian Standard IS-516 (equivalent to ASTM C469). The PCC is generally constructed over a 150 mm (6’’) thick stabilized base layer of Dry Lean Concrete (equivalent to P-304) over 600 mm (23.5’’) to 1,000 mm (40’’) thick granular subbase (equivalent to P-154). The minimum pavement thickness analyzed for design purposes was 400mm (15.75”) P-501 PCC on 150mm (6”) P-304 CTB on 850mm (33.5”) P-154 granular subbase. The total pavement thickness is 1,400mm (55”).

The existing flexible pavements do not show any major signs of distress, apart from routine surface defects requiring ongoing maintenance such as oxidation, raveling and minor bleeding. The existing flexible pavements consist of approximately 650 mm (25.5”) of asphaltic concrete wearing course / base course (P-401) over approximately 750 mm (29.5”) granular base / subbase (P-209 and P-154). The total pavement thickness is 1,400mm (55”).

The bore logs established the presence of rock strata under the pavement at depths varying from 1,750 mm (69”) on the western side of the apron to 5.5 m (18 ft) on the eastern side. The subgrade layer above the rock strata consists of residual soil which has been classified as Silty Clay with low to high plasticity (USCS CL – CH). The correlated CBR calculated from field N value readings for the subgrade soil varied from 1.6% to 2.5%. The water table in the area varies seasonally between 2 m (6.5 ft) to 3 m (10 ft), as per the Peisometer readings taken over the year 2008-2009. For design purposes, a subgrade CBR value of 2% and a k value of 11 kPa/mm (40 pci) were adopted.

SUBBASE PREPARATION OPTIONS

The new international apron is to be constructed from rigid Portland Cement Concrete (PCC) pavement, with the exception of the head of stand road, ground service equipment storage areas and taxiway shoulders, all of which will be constructed from asphaltic concrete surfaced flexible pavement. Rigid pavements are preferred for the aircraft parking stands and taxilanes due to the very high stresses that heavily weighted slow moving and static aircraft place on the pavement, and due to fuel and oil spills that can occur from maintenance and refueling operations on the apron stands.

The footprint of the new apron lies over existing flexible & rigid pavements, former buildings sites and grass areas. The levels of the proposed pavements vary significantly from the existing levels, with the majority of the areas needing to be raised to meet the design profile. As such, it became evident that a large quantity of the existing pavements could be reused as subbase for the new apron pavement in order to provide an economical alternative to full depth reconstruction of the entire apron. Full depth reconstruction would only be required in areas currently occupied by buildings or grass islands, or in areas of cut where insufficient cover over subgrade could not be achieved.

A number of options were investigated for economical reuse of the existing pavements, including reuse of existing intact pavements, bonded & unbounded concrete overlays, cracking & seating of existing PCC pavements, rubblization of existing PCC pavements, reuse of existing subbase and recycling of PCC and asphaltic concrete materials. The following paragraphs discuss the technical merits of each of the subbase preparation options considered in the design. The pavement sections adopted for pavement thickness design are shown in Table 1 below.

Reuse of Existing Intact Pavements. Intact existing pavements could only be reused in areas where the proposed levels matched the existing levels, and provided that the condition and structural capacity of the existing pavements would provide an adequate design life without significant maintenance or replacement. After reviewing these factors it was decided that the areas that could be reused were insufficient to warrant implementation of this option.

Bonded Concrete Overlays. Bonded concrete overlays could be used where the existing rigid pavements were in very good condition, where the joint pattern of the existing slabs matched the proposed joint layout of the new pavement, and where the vertical geometric profile of the proposed surface matched the existing surface profile, to avoid varying thicknesses of the overlay. After reviewing these factors, it was decided that this option was not feasible.

Unbonded Concrete Overlays. Unbonded concrete overlays could be used where the existing rigid pavements were in very good condition and the vertical geometric profile of the proposed surface was similar to the existing surface profile, to avoid thick asphaltic concrete profile correction courses being constructed between the two rigid pavements. After reviewing the relative levels of the proposed and existing surfaces, it was decided that the profile correction courses would be uneconomical and unfeasible.

Cracking & Seating of Existing PCC Pavements. Cracking and seating of existing PCC pavements is generally utilized if the overlay material is intended to be asphaltic concrete. In our case, the overlay material was intended to be PCC. In order to avoid a sandwich pavement, the profile correction course would need to be a stabilized material such as P-401 asphaltic concrete or P-304 cement treated base. Not only was this correction course determined to be uneconomical, it would result in an extremely stiff subbase on which to construct the new PCC, which could lead to early-age distress such as top-down cracking. After reviewing these factors, it was decided that this option was not feasible.

Rubblization of Existing PCC Pavements. Rubblization of existing PCC pavements is generally utilized if the overlay material is intended to be asphaltic concrete, and there were no known examples of new rigid pavements being constructed over a rubblized concrete pavement.

After careful consideration it was decided that the rubblization process would shatter the existing PCC slabs sufficiently to eliminate the slab action of the existing PCC pavement, thereby reducing the likelihood of reflection cracking from the underlying layers. Since the rubblized material is effectively granular in nature, the profile correction course could be constructed from granular materials (P-209 and P-154) without the section acting as a sandwich pavement, and therefore this option was considered to be feasible.

Reuse of Existing Subbase. The existing subbase could be reused insitu after removal of asphaltic concrete or PCC wearing courses provided that the subbase was of sufficient thickness to provide the required cover over subgrade and of sufficient quality. After analyzing the strength of the existing sections, it was decided to retain a minimum of 600mm (23.5”) of existing subbase under the new PCC and stabilized base course layers. This option was considered to be more economical and environmentally responsible than importing new subbase materials. Accordingly, this option was considered to be feasible.

Full Depth Reconstruction. Full depth reconstruction would be required in areas where neither rubblization of existing PCC pavements or retention of existing subbase options were feasible. This would occur in areas of cut, or areas currently occupied by buildings, shoulders and grass islands.

Recycling of PCC and Asphaltic Concrete Materials. In areas where existing asphaltic concrete or PCC wearing courses were to be removed, recycling of the materials for reuse as a subbase course was investigated. Vendors were identified that could provide mobile crushing plants on site that could crush PCC and asphaltic concrete into a material with equivalent properties to subbase (P-154) quality material. As an alternative, the existing asphaltic concrete could be removed by cold milling and the milled material could also be used in lieu of P-154 material. Both methods were considered to be more economical and environmentally responsible than importing new subbase materials. Accordingly, this option was considered to be feasible.

Table 1.
Pavement Sections Adopted for PCC Thickness Design.

Layer	**PCC over Rubblized Concrete**	**PCC over Existing Subbase**	**PCC Full Depth Reconstruction**
Wearing Course	P-501 PCC	P-501 PCC	P-501 PCC
Stabilized Subbase	150mm (6”) P-304 CTB	150mm (6”) P-304 CTB	150mm (6”) P-304 CTB
Crushed Aggregate Capping Layer	200mm (8”) P-209 crushed aggregate base course	200mm (8”) P-209 crushed aggregate base course	200mm (8”) P-209 crushed aggregate base course
Profile Correction Course	P-154 (or equivalent) aggregate subbase	P-154 (or equivalent) aggregate subbase	P-154 (or equivalent) aggregate subbase
Subbase / Select Fill	Rubblized PCC, E=1,400 MPa (200,000 psi) and underlying subbase	Retained existing P-154 equivalent aggregate subbase	900mm of Select Fill CBR 6%
Subgrade	k = 11 kpa/mm (40 pci)	k = 11 kpa/mm (40 pci)	k = 11 kpa/mm (40 pci)

AIRCRAFT TRAFFIC ANALYSIS

The rigid pavements were designed for a 30 year life, and the annual traffic was considered for both the taxilanes and aircraft parking stands to enable a comparison of the results. The traffic was estimated based on a detailed analysis of the aircraft parking layout and predicted operating modes of the apron. The new T2 terminal building will operate Multiple Aircraft Ramp System (MARS) stands and swing gates, so that a single stand can accommodate either one wide body aircraft or two narrow body aircraft, in either domestic or international configuration. Accordingly, the parking stands were categorized into three main groups based on the likely operating scenario of the apron and terminal building; dedicated international usage, dedicated domestic usage, and mixed international / domestic usage. In addition, the taxilane traffic was split into 8 different segments and traffic was calculated according to the estimated usage of stands being fed from each of the 8 taxilanes. The layout of the apron is shown in Figure 2 below.

CSIA currently handles approximately 550 daily air traffic movements (arrivals and departures), however this usage is forecast to increase to 888 daily movements by 2015. The 2015 forecast usage represents the constrained capacity of the airport, hence traffic is expected to remain constant after this time. The most likely aircraft fleet mix for the airport was determined from traffic forecast reports commissioned by MIAL, and is shown in Table 2 below.

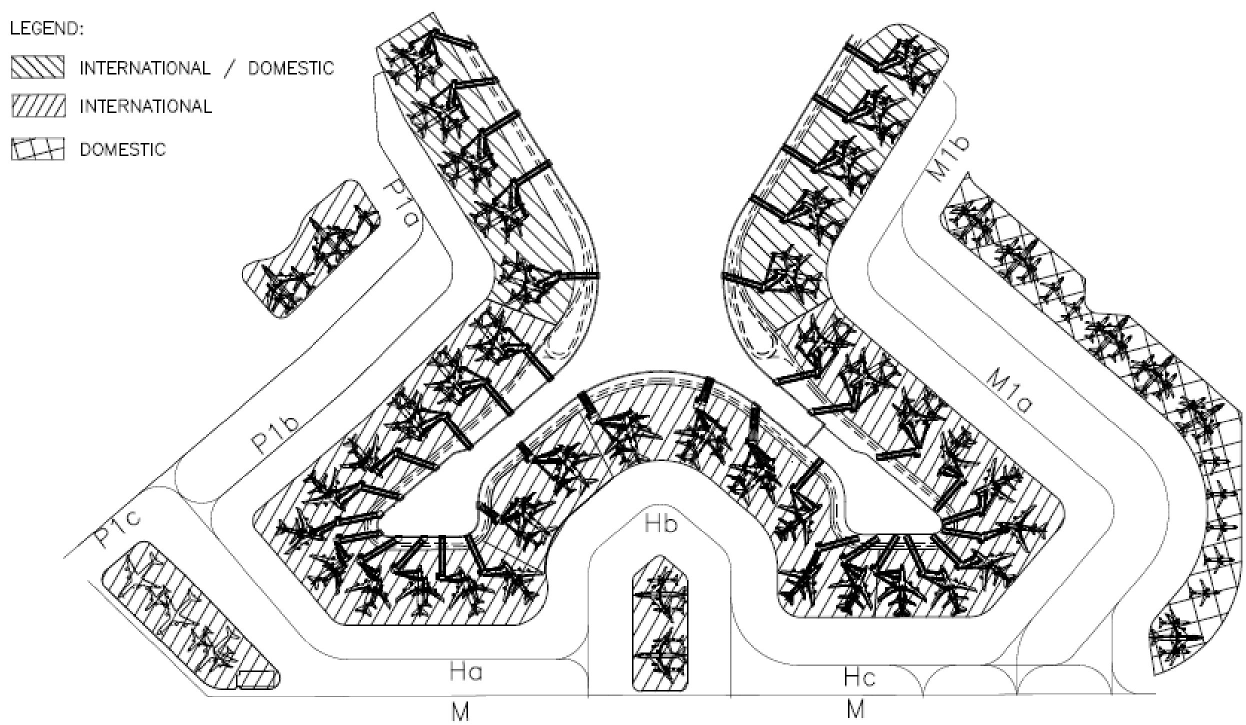

Figure 2. T2 Apron Layout with Taxilanes and Operational Scenario Groups.

Table 2.
CSIA Aircraft Fleet Mix Percentages.

Aircraft	A320	A321	A300	A330	A340-300	A340-600	A380
Fleet Mix	16.7%	2.3%	10.7%	10.7%	4.1%	4.1%	0.3%
Aircraft	B737-800	B767-400	B747-400	B747-8	B777-300	B777-300ER	MD11
Fleet Mix	26.0%	5.6%	5.9%	0.3%	8.2%	3.4%	1.8%

The above fleet mix was not apportioned to aircraft stands, as airlines tend to have preferred stands and some stands may be utilized more throughout a day than others. Consequently, regardless of whether a stand is used for international or domestic aircraft, that stand may be used to service a large mix of aircraft types, or it may be used predominantly to service only a few aircraft types. Certain stands on each apron area may be allocated to the predominant airlines (or a specific ramp handler), which may operate a limited fleet range. Hence, it is reasonable to expect that a stand may be subjected to regular usage of critical wide and narrow body aircraft types rather than the full airport fleet mix. Based on the fleet mix and flight schedules provided by the capacity study, it was clear that the major domestic operators were favoring B737-800 and A320/1 aircraft, and the major international operators were favoring B777-300, B777-300ER and A330-300 aircraft. After careful consideration of these factors, we determined that the following fleet mixes would represent the most likely worst case traffic situations for the apron.

- Dedicated International Fleet Mix – 30% B777-300ER, 40% B777-300, 30% A330-300.
- Dedicated Domestic Fleet Mix – 12.5% A330-300, 12.5% B777-300, 37.5% A321, 37.5% B737-800.
- Mixed International & Domestic Fleet Mix – 4.3% B777-300ER, 5.6% B777-300, 4.3% A330-300, 42.9% A321, 42.9% B737-800.

The annual taxilane usage was calculated for each of the 8 taxilanes based on the daily airport traffic, aircraft fleet mix and taxilane usage factors. The taxilane usage factors are expressed as the percentage of narrow body and wide body stands that can be accessed via each taxilane. The following formula represents the calculation of the annual taxilane usage for any given taxilane and for any given aircraft type:

$$T_a = T_{da} \times P_{fm} \times P_{tuf} \times 365$$

Where:
- T_a = Annual departures of particular aircraft type for specific taxilane
- T_{da} = Total daily airport departures
- P_{fm} = Percentage of aircraft fleet mix applicable to aircraft type
- P_{tuf} = Percentage based taxilane usage factor for specific taxilane

The calculated annual departures for each taxilane are shown Table 3 below:

Table 3.
Annual Departures for each Taxilane.

	P1$_a$	**P1$_b$**	**P1$_c$**	**H$_a$**	**H$_b$**	**H$_c$**	**M1$_a$**	**M1$_b$**
A320	7,624	17,790	17,790	0	1,271	3,812	13,978	7,624
A321	1,054	2,460	2,460	0	176	527	1,933	1,054
B737-800	11,599	27,064	27,064	0	1,933	5,799	21,265	11,599
A300	896	4,181	5,674	2,389	2,389	1,493	4,181	896
B767-400	473	2,207	2,995	1,261	1,261	788	2,207	473
A330	896	4,181	5,674	2,389	2,389	1,493	4,181	896
A340-300	348	1,626	2,207	929	929	581	1,626	348
A340-600	348	1,626	2,207	929	929	581	1,626	348
B747-400	373	1,742	2,364	995	995	622	1,742	373
B777-300	662	3,089	4,193	1,765	1,765	1,103	3,089	662
B777-300ER	284	1,324	1,797	757	757	473	1,324	284
A380	0	0	0	0	365	73	0	0
B747-8	0	0	0	0	365	73	0	0

The annual parking stand usage was calculated for each of the 3 operating scenario groups (dedicated international, dedicated domestic and mixed international / domestic), based on the daily stand usage, stand fleet mix and Pass to Coverage Ratio correction factor. FAARFIELD assumes a normal distribution of aircraft wander about the pavement centerline, however the degree of wander experienced on aircraft parking stands is typically very small due to the use of Visual Docking Guidance Systems and nose-wheel guidance cameras. To account for this, adjustments were made to the traffic figures to artificially account for the inbuilt PCR factors used by FAARFIELD.

International passenger aircraft typically take longer to service than domestic aircraft. As a worst case scenario an international stand could service 8 aircraft per day, a domestic stand could service 16 aircraft per day, and a mixed stand could service 14 aircraft per day. The following formula represents the calculation of the annual parking stand usage for any given operating scenario group and for any given aircraft type:

$$T_a = T_s \times P_{fm} \times PCR \times 365$$

Where:
- T_a = Annual departures of particular aircraft type for specific stand
- T_s = Total daily stand departures
- P_{fm} = Percentage of stand fleet mix applicable to aircraft type
- PCR = Pass to Coverage Ratio correction factor

The calculated annual departures for each operating scenario group are shown Table 4 below:

Table 4.
Annual Departures for each Parking Stand Operating Scenario Group.

	Pass to Coverage Correction Factor	Dedicated International	Dedicated Domestic	Mixed Int. & Domestic
B777-300	4.13	4,824	3,015	1,206
B777-300ER	3.86	3,381	0	845
A330	1.88	1,647	1,372	412
A321	3.46	0	7,577	7,577
B737-800	3.53	0	7,731	7,731

PAVEMENT DESIGN USING FAARFIELD

Designs were conducted using FAARFIELD based on taxilane and parking stand traffic, and the results are presented in Table 5 and Table 6 below.

Table 5.
Calculated PCC Thicknesses based on Taxilane Traffic.

Taxilane	Rubblization of Existing PCC		Retention of Existing Subbase		Full Depth Reconstruction	
	mm	Inches	mm	Inches	mm	Inches
P1a	N/A	N/A	450	17.75	440	17.25
P1b	N/A	N/A	485	19	475	18.75
P1c	N/A	N/A	490	19.25	485	19
Ha	335	13.25	470	18.5	460	18
Hb	335	13.25	470	18.5	465	18.25
Hc	N/A	N/A	460	18	455	17.75
M1a	380	15	480	19	475	18.75
M1b	335	13.25	450	17.75	440	17.25

Table 6.
Calculated PCC Thicknesses based on Parking Stand Traffic.

Operating Scenario Group	Rubblization of Existing PCC		Retention of Existing Subbase		Full Depth Reconstruction	
	mm	Inches	mm	Inches	mm	Inches
Dedicated International	375	14.75	485	19	475	18.75
Dedicated Domestic	325	12.75	445	17.5	435	17
Mixed International & Domestic	N/A	N/A	455	17.75	445	17.5

The design PCC thicknesses computed based on taxilane traffic and aircraft stand traffic were found to be comparable, and therefore as per standard practice, the design thicknesses as computed for taxilane traffic were adopted for both the taxilane pavements and adjacent parking stands.

Construction costs could be optimized by adopting varying PCC thicknesses for each taxilane and adjacent parking stands, however in view of practical considerations and simplification of formwork and construction methodology, three standard PCC thicknesses were adopted across the apron. The PCC thicknesses adopted for construction were 400mm, 450mm and 485mm as per Table 7 below. Although the thicknesses computed for the new PCC over rubblized existing PCC subbase were in the range 335mm to 380mm (13.25” to 15”), it was considered prudent to adopt a minimum PCC thickness of 400mm (15.75”) in order to allow for some conservatism in the design and to mitigate against possible additional warping and curling stresses associated with a thinner pavement over a comparatively stiff subbase.

Table 7.
PCC Thicknesses Adopted for Construction.

Taxilane	Rubblization of Existing PCC		Retention of Existing Subbase		Full Depth Reconstruction	
	mm	Inches	mm	Inches	mm	Inches
P1a	N/A	N/A	450	17.75	450	17.75
P1b	N/A	N/A	485	19	485	19
P1c	N/A	N/A	485	19	485	19
Ha	400	15.75	485	19	485	19
Hb	400	15.75	485	19	485	19
Hc	N/A	N/A	485	19	485	19
M1a	400	15.75	485	19	485	19
M1b	400	15.75	450	17.75	450	17.75

PAVEMENT SECTIONS FOR NEW RIGID PAVEMENTS

The relative costs of each feasible option were considered in detail, including the cost of placing profile correction courses and the wearing course over the insitu / recycled subbase in order to ascertain the cost benefits of each method. The initial basic cost comparison determined that insitu rubblization of existing PCC pavements was the most economical solution, followed by retention of the existing subbase with recycled subbase correction courses. Full depth reconstruction was the least economical solution.

From the pavement thickness design analysis it was determined that the subgrade treatment options were dictated by the existing pavement structure as well as the relative level difference between the existing and proposed pavements. The following points were determined from the analysis for selection of the most appropriate pavement types for each of the apron areas:

- Rubblization of existing PCC pavements could occur in areas of existing rigid pavements where the level difference between the proposed and existing surfaces was adequate for accommodating the new PCC and stabilized subbase (P-304 CTB) thicknesses. Following a review of the pavement thickness required our analysis showed that this pavement section could occur where the level difference was in excess of 550mm (21.75") in fill. The 550mm lower limit consists of new 400mm (15.75") PCC and 150mm (6") P-304 CTB, as depicted in Figure 3 below. For level differences greater than 550mm, a profile correction course would be constructed using recycled PCC or asphaltic concrete subbase materials. In the event of a shortfall in recycled products, P-154 material would be imported from off site.

- Retention of existing subbase could occur if the area had sufficient thickness of subbase to provide cover over the subgrade after removal of the asphaltic concrete and/or PCC wearing courses. Following a review of the pavement thickness required it was calculated that this pavement section could occur where the level difference was between -165mm (6.5") in cut and 550mm (15.75") in fill for existing rigid pavements, or above -165mm (6.5") in cut for existing flexible pavements. The -165mm lower limit consists of 485mm P-501 PCC + 150mm P-304 CTB + 600mm P-154 existing granular subbase – 1,400mm existing pavement thickness, as depicted in Figure 3 below. For level differences above -165mm in cut, a profile correction course would be constructed using recycled PCC or asphaltic concrete subbase materials. In the event of a shortfall in recycled products, P-154 granular subbase would be imported from off site.

- Full depth reconstruction could occur in areas below -165mm (6.5") in cut, or where existing buildings, shoulders or grass islands were present. In consideration of the plastic and swelling nature of the subgrade soil identified through geotechnical investigations, the pavement design incorporated replacement of 900mm (3ft) of existing subgrade with select fill material of CBR 6% minimum, as per the guidelines provided in Table 3-7 of FAA Advisory Circular 150/5320-6E [5].

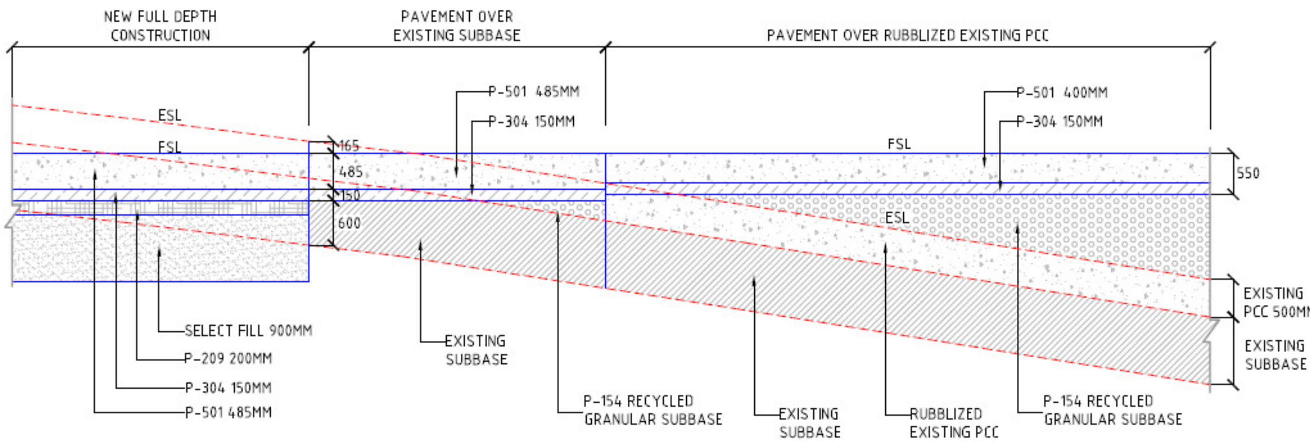

Figure 3. Transitions between Full Depth Reconstruction, Keep Subbase and Rubblization.

A final challenge existed in that the existing fuel hydrant main (which was to remain operational throughout the construction) ran beneath the site. As the operating fuel companies prohibited the use of vibrating rollers and rubblization equipment within 3m (10ft) of the pipeline, these areas were designed specifically to protect the pipeline.

The proposed surface levels were modeled in the 3-dimensional geometric design software program 12D. At the completion of the geometric design, a full 3-dimensional triangulation model was prepared of both the existing and proposed surfaces, and tin-to-tin depth contours were prepared to show the relative depths between each surface. From this output the designers were able to trace the -165mm (6.5") cut and 550mm (15.75") fill contours on a layout plan in order to determine the point at which the type of subbase preparation transitioned from full depth reconstruction to retention of existing subbase to rubblization of existing PCC pavements.

The final step in the design optimization process was to optimize the new terminal building floor level and apron gradients in order to judge the effect on pavement material quantities and associated cost benefits. The aim of this exercise was to achieve a balance between raising the levels sufficiently to maximize the rubblization area, whilst limiting the volume of profile correction course material.

The final areas of the various subbase treatment options achieved for the apron reconstruction are presented in Table 8.

Table 8.
Subbase Treatment Areas.

Subgrade Treatment	**Area (m^2)**	**Area (ft^2)**
Rubblization of Existing PCC	535,000	5,759,000
Retention of Existing Subbase	155,000	1,668,000
Full Depth Reconstruction	220,000	2,368,000
Construction over Existing Fuel Line	30,000	323,000
Total	**940,000**	**10,118,000**

CONCLUSION

The paper has highlighted the complexity of the apron pavement design and construction staging at Mumbai International Airport. The operational constraints of this project have resulted in the requirement to construct the apron in a series of discreet stages, and it is important to recognize the need to implement advanced planning, monitoring and control techniques in order to maintain the project schedule in a very challenging operational environment.

With an aim to economize the pavement design and construction time, the existing apron pavement layers have been utilized wherever feasible, in consideration of the vertical geometry of the apron and structural requirement for supporting the design aircraft traffic. The design optimization approach adopted for this project resulted in pavement sections comprising of construction over rubblised PCC, construction on existing subbase, and full depth construction. The proposed construction of rigid pavements over rubblised PCC is a highlight of this project and the performance will be monitored to provide for future guidelines.

The design aircraft traffic was derived on the basis of a detailed traffic analysis and also on the basis of the critical aircraft traffic on stands corrected for pass to coverage factors. The design thicknesses established for both the traffic scenarios were found to be comparable. It is generally accepted practice to design an apron based on the taxilane traffic and to adopt the same thickness for the parking stands. As the relative traffic on taxilanes and stands may vary depending on the number of stands serviced by a particular taxilane, it is recommended to check both scenarios and to adopt the higher thickness.

This project is a true reflection of how sound engineering can, in times of economic crisis, be an aid to an airport by providing innovative solutions, detailed analyses and optimization of designs. Larsen & Toubro would like to acknowledge the support of the GVK Group, Mumbai International Airport Limited, and CH2MHILL (Project Management Consultants) for the production of this paper and their support in adopting innovative and non-standard designs.

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