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Renforcement de la piste de l'aéroport de Genève au-dessus du tunnel de Ferney

Upgrade of Geneva airport runway – the Ferney Tunnel

Jean-François Klein

Introduction

La réfection et le remplacement de la piste de l'aéroport de Genève au droit du tunnel de Ferney ont pu être effectués grâce à la mise en œuvre de techniques inédites et originales exploitant au mieux les matériaux à disposition et la technologie du béton et de la précontrainte.

La dalle du tunnel a été remplacée par un système de poussage cadencé intervenant durant les horaires restreints de fermeture nocturne de la piste, soit entre 0h00 et 05h00 du matin. Durant toute la durée du chantier, les avions ont décollés et atterris sur une dalle posée sur des patins glissants soutenue par un étayage complexe et sécurisé par des vérins latéraux de guidage.

A l'issue de l'opération, le bilan est très positif : l'ouvrage a été réalisé selon les budgets annoncés, et surtout, sans aucune perturbation du trafic aérien et de l'exploitation de l'aéroport. Aucun vol n'a été ni retardé, ni détourné. De plus, toutes les dispositions avaient été prises pour permettre l'accueil éventuel de vols d'urgence tels que les vols sanitaires, même durant les opérations nocturnes de travaux.

Une opération complexe où la qualité de la préparation initiale du dossier et du projet est primordiale, tout comme la collaboration et la synergie entre les différents intervenants, qu'ils soient exploitants de l'aéroport, exploitants du domaine routier, ingénieurs ou entreprises.

Introduction

The renovation and replacement of the Geneva airport runway above the Ferney tunnel were achieved by means of unique and unprecedented techniques, using in the most optimal method, available materials as well as concrete and prestressing technologies.

The tunnel slab was replaced using an incremental launching method, occurring only during the limited hours of runway closure at night, that is between 12:00 pm and 5:00 am. During the whole construction period, aircraft took off and landed on a slab laid on sliding bearings, supported by a complex shoring system, and secured by lateral guiding jacks.

The project was completed very successfully: estimated costs were met, and above all air traffic was never disturbed, nor were airport operations. No flight was delayed or rerouted. Besides, specific measures had been taken to ensure emergency flights landings, such as air-ambulance flights, even during construction hours at night.

Such a complex operation relies on a thorough preparation of the project, as well as a very good

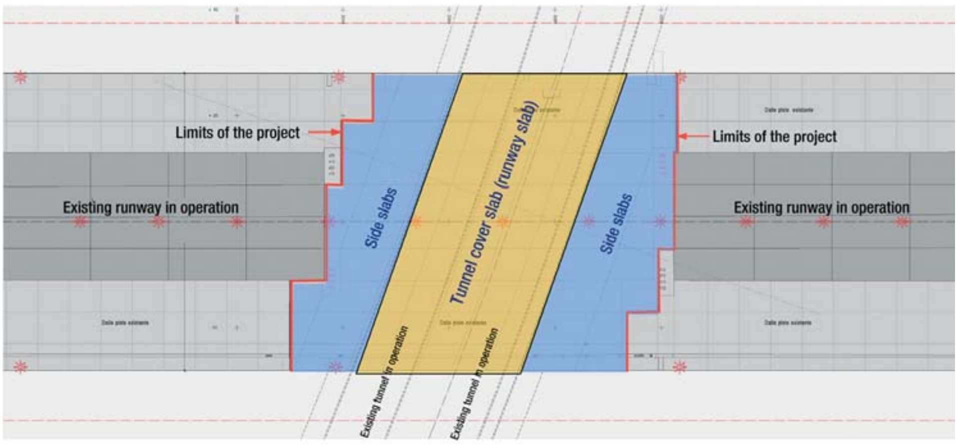

Fig. 1
Situation du tunnel et de la piste de l'aéroport.
Situation of the tunnel and the runway.

Problème spécifique du tunnel de Ferney

La construction du tunnel de Ferney a été imposée par la prolongation de la piste en 1962. Il s'agit d'une tranchée couverte de plus de 400 m de longueur croisant la piste en son milieu. La toiture du tunnel forme directement la structure de la piste d'envol.

Le tunnel a été dimensionné pour supporter les charges d'un avion de 200 t avec des réactions maximales par bogie de 125 t. Dans les années 70, à l'arrivée des Jumbo-jet, d'un poids maximal de 400 t, une expertise utilisant les nouveaux moyens informatiques de l'époque a permis de démontrer que les réserves de capacité au centre de la piste étaient suffisantes pour permettre l'accueil de ce type de gros porteurs sur l'aéroport de Genève.

En 2005, plusieurs paramètres ont incité l'aéroport de Genève à engager des travaux de grande importance permettant la réhabilitation de la piste au droit du tunnel :

1. La dégradation de l'état de surface de la piste est en voie d'accélération et pourrait poser rapidement un problème de sécurité pour les utilisateurs.
2. Le développement de l'aviation civile incite les constructeurs a produire des avions de taille supérieure (600 t). La toiture du tunnel dans son état actuel est

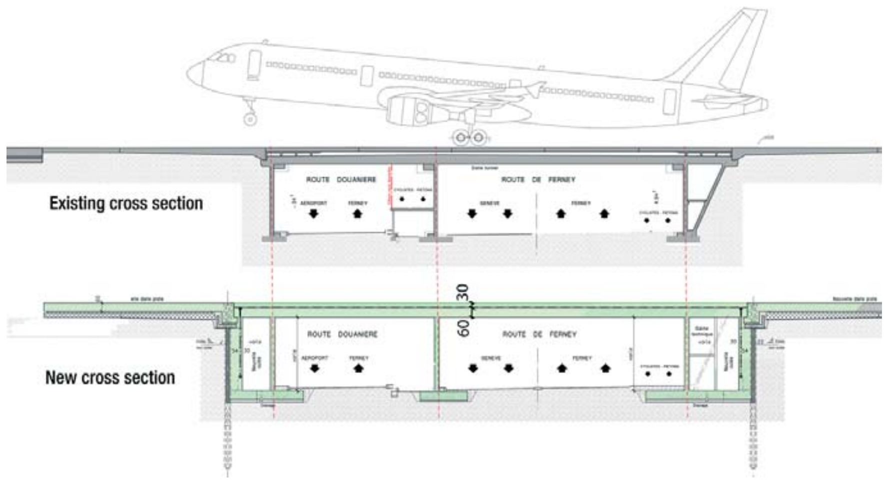

Fig. 2
Section existante et section future renforcée.
Old and new cross section.

coordination of the different people involved in the organization: airport operating services, road operating services, engineers and contractors.

Specific problem of the Ferney tunnel

The tunnel was constructed using the cut-and-cover method, intersecting the Geneva airport runway with a very shallow cover.
In that part, the runway (i.e. the tunnel cover slab) was designed to carry 200 ton aircraft, with a maximum load of 125 tons per bogey. In the 1970s, when Jumbo Jets with a weight of up to 400 tons came on the scene, an investigation of the tunnel carried out with new computer models available at the time showed that the structure was strong enough to withstand this type of aircraft.
In 2005, several factors led Geneva airport to initiate major works to renovate the runway around the tunnel:

1. The surface of the runway was in worsening condition, a safety issue became a growing concern.
2. Aircraft industry developments led to larger planes with a weight of 600 tons, starting 2007. The covering slab of the tunnel was unable to withstand such loads.

Two types of works were then envisioned:

1. Reinforcement of the part of the tunnel under the runway and renovation of the runway itself
2. Renovation of the whole tunnel, upgrading of electro-mechanical equipment, creation of emergency wall niches, and adaptation of the entrances.

incapable de supporter cette charge.
A cela se greffe le problème de l'entretien du tunnel qui n'a pas été effectué depuis de très nombreuses années. L'état de Genève, propriétaire de l'ouvrage souhaite profiter de ces travaux de grande envergure pour assurer la pérennité de l'ouvrage par un gros entretien ainsi que de procéder à la mise à jour des installations techniques et de sécurité. Les travaux engagés sont ainsi de deux natures :

1. Renforcement et entretien de la piste au droit du tunnel de Ferney.
2. Assainissement et gros entretien de l'ensemble du tunnel, mise à jour des installations électromécaniques, création de niches SOS et adaptation des portails d'entrée.

Augmentation de la capacité portante

L'augmentation de la capacité portante permettant de supporter les avions de 600 t (3 x la capacité portante du projet d'origine) a pu être obtenue par modification de la structure et utilisation de matériaux performants. Ainsi :

– La dalle portante est remplacée par une nouvelle dalle de 60 cm d'épaisseur en béton à haute performance, fortement précontrainte dans les deux directions
– Des encastrements puissants avec précontrainte verticale

Increase of the loading capacity

The increase of the loading capacity for 600 ton aircraft (3 times the original one) was achieved by modifying the structure and using better materials:

– The new 60 cm-thick slab is highly pre-stressed in two directions
– Strong fixed ends of the slabs are ensured by vertical pre-stressing in new abutment walls behind the bearing walls of the tunnel. This increases significantly the global stiffness.
– The runway slabs are cast with high strength concrete

Description of the methods used

In order to achieve the replacement while meeting the schedule constraints, a launching method was used, replacing progressively the former slab. The work on the runway surface was then limited to what is usually done to replace the runway slab in other parts on the ground.
The sequence of construction work can be sum up as follows (A–H):

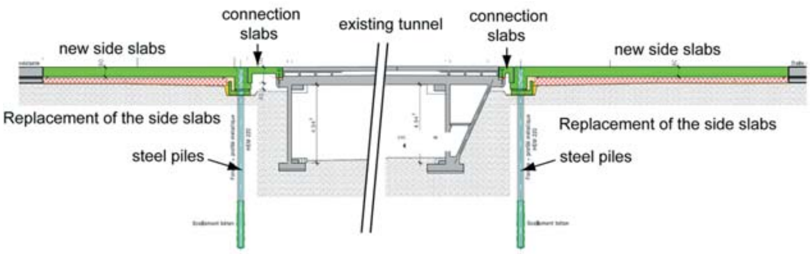

Fig. 3
Coupes en travers des dalles de bord.
Description of the lateral elements.

dans les murs sont créés sous forme de culées latérales à l'arrière des murs porteurs permettant une forte augmentation de la rigidité globale

Description de la méthode employée

La méthode développée pour mener à bien ces travaux dans le respect des contraintes (géométriques et d'exploitation) est une solution de poussage cadencé remplaçant progressivement la dalle actuelle. Les interventions de surface nécessaires pour mener à bien ces travaux sont ainsi très limitées. Les opérations principales peuvent être schématisées comme suit (A–H) :

A. Forage de pieux au travers de la piste actuelle de part et d'autres du tunnel.

Ces pieux serviront essentiellement aux phase de constructions afin de permettre la réalisation des culées du tunnel en taupe, sous la circulation des avions, en arrière des murs du tunnel en place et à l'abri d'une paroi berlinoise formée par les pieux métalliques. L'exécution de ces pieux a nécessité la mise au point de dispositifs spéciaux tels que l'emploi de couvercles préfabriqués en béton de 40 cm scellés à l'époxy rapide après le bétonnage du pieu permettant le passage immédiat des avions.

B. Remplacement des dalles de bords sur le terrain (dalles encore inchangées à ce jour), pose d'un élément provisoire de raccord entre les dalles de bord et la toiture actuelle du tunnel.

Les anciennes dalles de bord non armées sont soulevés à l'aide des portiques de grande capacité de l'aéroport, par le biais de centaines de goujons scellés dans le béton. Des éléments de 6 m de large par env. 14 m de long d'un poids de 120 à 160 t sont ainsi remplacés en une opération.

Les nouvelles dalles de bords sont posées sur un réseau de boudins gonflables à l'eau permettant de régler leur niveau et assurant leur positionnement pendant le temps de durcissement du coulis d'injection à prise rapide remplissant l'intervalle entre le remblai et la dalle de bord. L'extrémité de la dalle de bord présente un renfort avec un corbeau et des réservations venant s'enficher sur les têtes de pieux.

Un élément préfabriqué à géométrie variable posé entre le corbeau de la dalle de bord et le corbeau du tunnel existant sert de dalle de transition. Il permettra l'excavation entre le mur et la paroi berlinoise formée par les

A. Drilling of piles through the current runway slab on each side of the tunnel.

These piles are mostly used during the construction phase to build the abutments underground under the aircraft traffic. The abutments are built between the walls of the current tunnel and a Berlin-type wall (US: soldier pile wall) in between the steel piles. The drilling procedure uses special equipment like epoxy sealed 40 cm-thick concrete cover to allow immediate traffic on top of the just drilled and concreted pile.

B. Replacement of the runway slabs on each side of the tunnel (those had not been changed until now), and laying of a temporary link element between the side slabs and the tunnel slab.

The former side slabs (containing no reinforcement steel bars) are lifted up by a high capacity travelling crane from the airport, using hundreds of dowels sealed in the concrete. 6 m-wide by 14 m-long elements are thus removed in one operation.

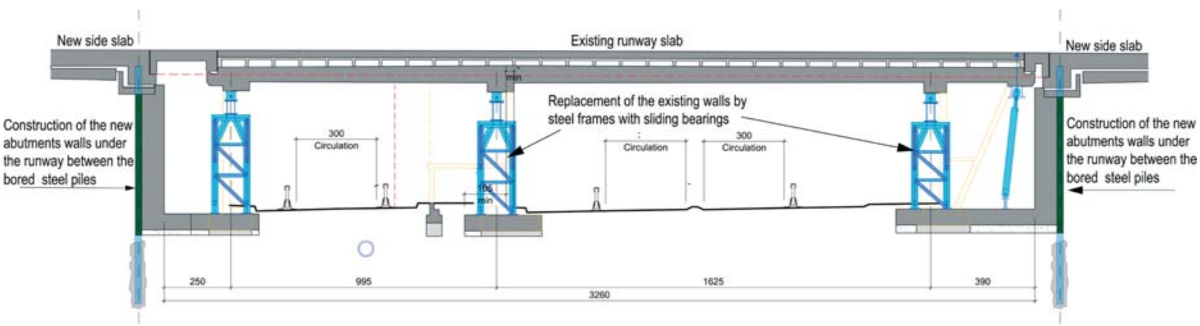

Fig. 4
Construction des nouvelles culées en arrière des murs actuels – étayage temporaire de la dalle actuelle avec appuis glissants.
Construction of new abutment walls next to the Berlin-type wall – temporary shoring under the runway slab.

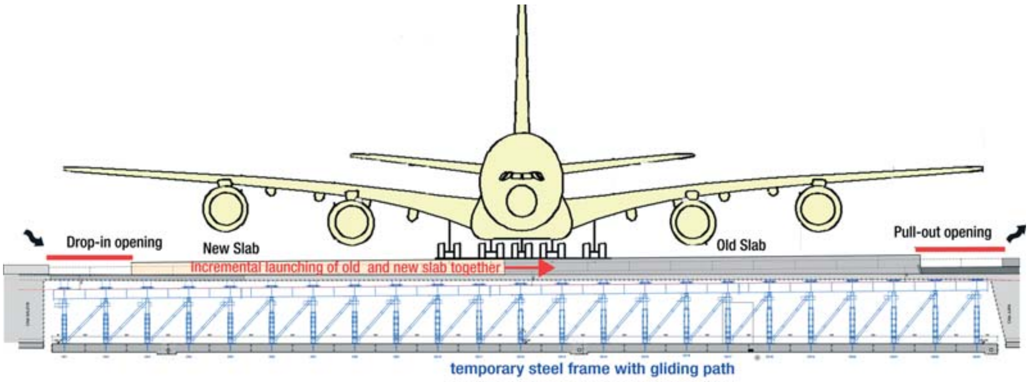

Fig. 5
Elévation de l'étayage, situation des trémies de pose et d'évacuation.
Cut and removal of an element to create openings on each side of the runway.

The new side slabs are then laid on water-inflated tubes, allowing them to adjust their height and position before the space between the ground and the slab is filled with rapid-setting grout. The end of the side slab next to the tunnel has a reinforced corbel with holes enclosing the steel piles' top ends.
C. Construction of the new abutments underneath, while keeping the clearance free for traffic in the tunnel. This work is carried out next to a Berlin-type wall in between the steel piles.

pieux tout en assurant le passage des avions. Cet élément permet également de compenser les effets de la courbure du tunnel et de faire un ripage rectiligne malgré la courbure.
C. Construction en taupe de nouvelles culées sous la piste actuelle et à l'intérieur du gabarit du tunnel. Exécution de ces travaux à l'abri du bouclier formé par une paroi berlinoise réalisée entre les pieux forés au travers de la piste.
D. Pose d'un étayage provisoire supportant l'ancienne dalle de toiture du tunnel. Cet étayage est

D. Demolition of the tunnel walls, replaced by temporary shoring, bearing the current slab of the tunnel.
This steel shoring, replacing the tunnel walls is designed to progressively transfer the aircraft loads, while disconnecting the slab to be pushed out.
E. Creation of two large openings in the tunnel slab on each side of the runway.
On each side of the runway, outside the aircraft traffic, two openings are created. They are 8 and 10 m long, and are as wide as the

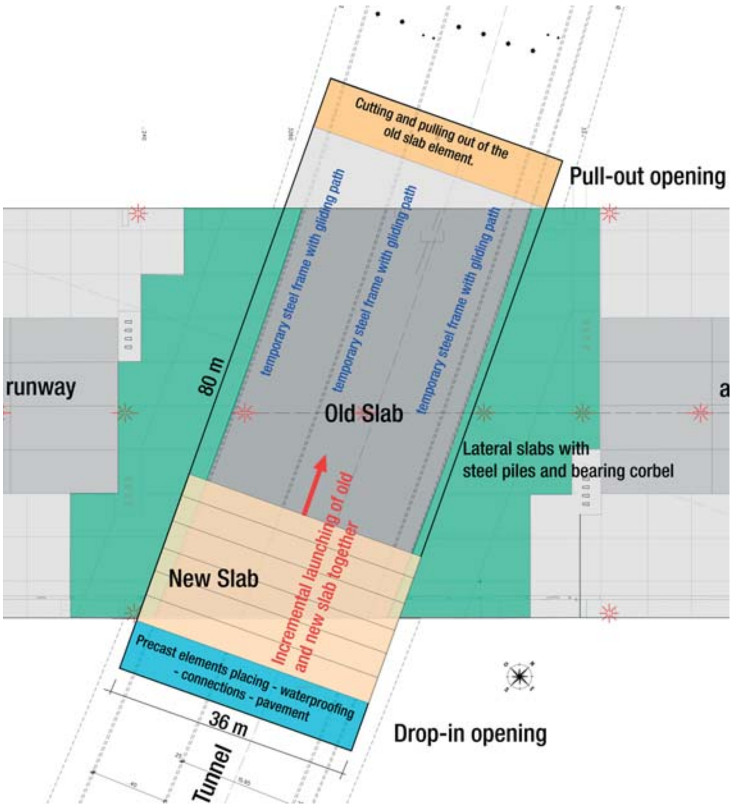

Fig. 6
Principe général de la méthode de ripage.
General principle of the launching method.

Fig. 7
Pose d'un nouvel élément dans la trémie – collage époxy et post-tension des éléments à joints conjugués.
Laying a new element in the opening – epoxy sealing and post-tensioning connection against the previous one.

au droit des anciens murs et assure progressivement la reprise des efforts. La totalité de la dalle est ainsi désolidarisée de ses murs et posée sur des voies de ripage.

E. Ouverture de deux trémies dans la dalle du tunnel de part et d'autre de la piste.

De part et d'autre de la piste, en dehors des zones de circulation des avions, deux ouvertures de 8 et 10 m de longueur sur toute la largeur du tunnel sont créées. Ces ouvertures serviront à poser les nouveaux éléments préfabriqués de dalle d'un coté et de d'enlever les anciens de l'autre coté après la phase de poussage. En phase opérationnelle de l'aéroport, ces ouvertures sont protégées par des couvercles métalliques coulissant sur des rails capables de supporter les charges des avions en cas de sortie de piste. Ces « tiroirs » sont ainsi ouverts et fermés en fonction des heures d'exploitation de la piste d'envol.

F. Pose d'éléments préfabriqués de dalle précontrainte, étanchéité, bétonnage de la dalle d'usure et évacuation de l'ancienne dalle.

Dès l'atterrissage du dernier avion vers 23h45, le couvercle de protection de la trémie de pose est ouvert. Le portique de levage dépose un élément préfabriqué de dalle de 36 m de longueur par 3 m

tunnel. They are used to lay new precast slab sections on one side, and to remove old sections on the other side after each launching step. During the day when the airport is running, these openings are covered with steel plates sliding on rails, which are capable of taking the load of an aircraft (in case a plane accidentally exits the runway). These sliding covers are opened and closed according to the air traffic hours on the runway.

F. Laying of new precast prestressed slab sections, proofing layer, casting of runway top concrete, removal of the old section of the current slab.

As soon as the last aircarft lands around 11:45 pm, the opening cover is slid out. The travelling crane brings a new 36 m-wide by 3 m-long slab section and puts it in the opening. This section is fixed to the previous one by epoxy sealing and post-tensioned using thirty 50 mm diameter bars connected to the previous section. After two of these elements are laid in the opening, giving 6 m of slab, the proofing layer is installed and the 30 cm-thick top concrete of the runway is cast.

On the other side of the runway, the 6 m-long old slab section pushed out is removed from the

de largeur dans la trémie. Celui-ci est connecté par collage époxy aux dalles précédentes et mis en précontrainte par une trentaine de barres diamètre 50 mm connectées à celles de l'élément précédent. Après la pose de deux éléments de dalles formant 6 m de nouvelle couverture du tunnel, l'étanchéité est complétée et la dalle d'usure de 30 cm d'épaisseur est bétonnée.

Du coté de la trémie d'évacuation, le morceau de 6 m de dalle précédemment poussé en dehors de la piste est découpé et évacué. La piste est rendue au trafic aérien à 05h30.

G. Ripage progressif de l'ancienne dalle et des nouveaux éléments par étapes de 6 m de longueur.

Tous les 6 m, l'ensemble de la dalle est poussée au travers de la piste, déplaçant ainsi la partie résiduelle de l'ancienne dalle vers la trémie de démolition, et introduisant les nouvelles dalles placées dans la trémie de pose dans le cheminement de la piste. La surface de roulement est ainsi progressivement remplacée sans intervention majeure dans le chemin d'évolution des avions. A la fin de chaque phase de ripage, des vérins de blocage latéraux intégrés dans l'épaisseur de la dalle viennent bloquer tout le système, afin que

Fig. 8
Vue de la piste après 3 étapes de ripage.
View of the runway after 3 pushing steps.

other opening. The runway is given back to air traffic at 5:30 am.

G. Progressive launching of the structure in six metre steps.

Every six metres, the structure is pushed across the runway, each time pushing a portion of the old slab out of the runway towards the demolition opening, and pushing in a portion of the new slab. Thus, the runway is replaced and reinforced gradually, without disturbing air traffic. At the end of every pushing step, lateral jacks are used to block the whole structure, so that aircraft can land and take off without creating any displacement of the slab laid on sliding bearings. With this system, even if there is a failure in the pushing system, the structure can be blocked and secured at any moment and the runway used by aircraft. In the case of the arrival of an emergency or air-ambulance aircraft, the runway can be ready in just a few minutes.

H. End of the pushing sequence, connection to the abutments.

Once the whole new structure is pushed in place, the back walls of the abutments are connected to

les avions puissent évoluer sur le tunnel sans risque de faire bouger la dalle posée sur ses appuis de glissement. De cette manière, même en cas de blocage du ripage, le système peut être à tout moment sécurisé et la piste exploitée. En cas d'arrivée impromptue d'un avion sanitaire ou d'urgence, la piste peut ainsi être opérationnelle en quelques minutes.

H. Fin du ripage, solidarisation des culées et de la dalle du tunnel.

A la fin du poussage, les murs arrières des culées sont connectés à la dalle par des barres de précontrainte verticales, formant ainsi des encastrement puissants permettant l'augmentation de capacité portante de la dalle. Ces murs remplacent progressivement les étayages qui sont démontés au fur et à mesure des transferts de charge sur les murs.

Au niveau de la dalle, de la précontrainte longitudinale complémentaire et continue complète les barres couplées. De même, dans la dalle d'usure, des câbles de précontrainte enfilés à la fin permettent de lutter partiellement contre les effets de la fissuration due aux effets différés.

the slab using vertical post-tensioning bars, creating strong fixed ends to the slab to increase the loading-bearing capacity. New walls gradually replace the temporary shoring, and this is then dismantled bit by bit once the load is transferred to the walls.

Additional longitudinal prestressing in the slab comes on top of the connected bars. Similarly, prestressing cables are slid into the top concrete of the runway to prevent cracking due to long-term effects.

Auteur/Author
Jean-François Klein
Dr ès sc. techn., ing. civil dipl. EPFL
Administrateur de T ingénierie sa
CH-1211 Genève
Email: gva@t-ingenierie.com

Pontili galleggianti in calcestruzzo precompresso sul Lago Maggiore

Floating landing stages in prestressed concrete on Lake Maggiore

Antonio Paronesso, François Prongué

Introduzione

Nell'ambito degli interventi di potenziamento delle infrastrutture destinate al turismo da diporto finanziate dalla Regione Lombardia, rivestono un ruolo importante le realizzazioni dei due pontili galleggianti di Porto Valtravaglia e Maccagno situati entrambi sulla sponda est del Lago Maggiore.
Ciascuna delle due strutture è formata da moduli prefabbricati in calcestruzzo armato assemblati in acqua per mezzo di un sistema di precompressione esterna. Grazie alla particolare forma ad arco e alla notevole mole del manufatto assemblato, le oscillazioni prodotte dal moto ondoso agente sulla struttura risultano contenute a tutto vantaggio di un notevole comfort per gli utilizzatori del molo.

Azioni esterne preponderanti

L'azione che genera le sollecitazioni più importanti all'interno di un corpo galleggiante è senz'altro il vento. Il suo effetto si esplica attraverso un'azione diretta rappresentata dalla pressione cinetica applicata alla struttura stessa e ai natanti ad essa ormeggiati ed un'azione indiretta rappresentata dal moto ondoso indotto dal vento.
I parametri che maggiormente determinano l'intensità di tali azioni e condizionano quindi il dimensionamento del sistema, sono l'estensione dello specchio d'acqua (fetch) e il regime dei venti della zona che si estende attorno alla struttura. Dal fetch e dalla durata dei venti nel tempo dipendono in particolare le lunghezze d'onda dei moti ondosi che si possono sviluppare in un determinato bacino. Dalle intensità dei venti dipendono in generale le altezze delle onde che possono impegnare la struttura.

Introduction

Within the scope of the works for the development of infrastructure for the tourist industry financed by the Region of Lombardy, the creation of two floating landing stages at Porto Valtravaglia and Maccagno play an important role. Both are situated on the east bank of Lake Maggiore.
Each of the two structures comprises prefabricated reinforced concrete modules assembled in the water by means of an external prestressing system. Thanks to the particular arched shape and considerable inertia of the assembled product, the oscillation generated by the movement of the waves acting on the structure proves to be contained for the great convenience of those using the jetty.

Main external action

The force which generates most stress inside a floating body is the wind. Its effect is developed through direct action represented by the kinetic pressure applied to the structure in question and to the craft moored to it as well as indirect action due to the movement of the waves, which the wind creates in the fluid accommodating the body.
The main parameters which determine the intensity of such action and therefore condition the dimensioning of the system, are the extent of open water (length of the free area available to the wind or fetch) and the wind speed (kinetic pressure) in the area that extends around the structure.
In particular, the length of the waves in the wave movement, which may be generated in a particular basin, depend on the fetch

Principali tipologie di moli galleggianti in calcestruzzo armato

Le tipologie di moli galleggianti in calcestruzzo armato attualmente impiegate per creare una darsena possono essere classificate in base al sistema di ormeggio utilizzato e in base alla rigidezza propria posseduta dalla struttura.
Con riferimento alle modalità di ormeggio, si possono distinguere un primo tipo di soluzioni che utilizzano sistemi di catene ancorate al fondo per mezzo di corpi morti o pali infissi e un secondo tipo di soluzioni che utilizzano sistemi di bielle rigide (o bracci oscillanti) ancorate al fondo per mezzo di pali.
Nel caso dei pontili in oggetto si è optato per la soluzione rigida del secondo tipo accoppiata ad un sistema di ormeggio formato da ben 34 catene opportunamente tesate ed orientate in modo da garantire spostamenti relativi fra passerella di accesso e corpo galleggiante entro le tolleranze di progetto.

Analisi

La struttura qui in esame ha il carattere di prototipo. Per la determinazione delle sollecitazioni interne indotte dal moto ondoso associato a diverse direzioni di

Aknowledge
La realizzazione delle opere illustrate nel presente articolo è stata resa possibile grazie al contributo fornito dallo Studio Ambrosetti-Colombo, Varese, Italia, da M. Jartoux, da Freyssinet SA Suisse e da AR&PA Engineering, Lugano Svizzera.

Fig. 1
Messa in acqua dei moduli per mezzo di un autogru.
Placing in the water of the modules by means of mobile crane.

and duration of the wind. In general, the height of the waves that could affect the structure depends on the intensity (kinetic pressure) of the wind.

Main types of floating jetties made of reinforced concrete

The types of floating jetties made of reinforced concrete currently used to create a dock can be classified according to the mooring system used and the inherent rigidity of the structure.
With regard to mooring methods, there is one type of solution, which uses systems with chains anchored to the bottom by means of anchor blocks or piles, and another type of solution, which uses systems with rigid connecting rods (or swivel arms) anchored to the bottom via piles.

propagazione d'onde, sono state effettuate analisi idrodinamiche in frequenza del solo corpo rigido galleggiante e analisi statiche e dinamiche non lineari nel tempo del sistema completo di catene.

Geometria del manufatto e tecnica costruttiva

Il molo è formato da 20 moduli prefabbricati in calcestruzzo armato di forma trapezoidale di lunghezza media 5,6 m, sezione trasversale di larghezza 4 m e altezza 3 m. I due moduli di testata si differenziano per organizzazione e dimensioni della struttura interna dagli altri 18 della zona centrale in quanto destinati ad accogliere le teste di ancoraggio dei cavi di precompressione. Lo spessore della soletta di fondo dei moduli è pari a 22 cm mentre quello della soletta superiore è delle

In the case of the landing stages in question, the rigid (i.e. second) type of solution was chosen coupled with a mooring system formed of 34 chains tightened and orientated so as to guarantee the relevant displacement between the access bridge and the floating body within the project tolerance range.

Analysis

The structure under consideration is like a prototype. In order to determine the internal stress induced by wave action coming from different directions, some hydrodynamic analyses were carried out in the frequency domain for the floating rigid body alone as well as non-linear static analyses and non-linear dynamic analyses performed in time domain for the system with chains.

Fig. 2
Ultime operazioni di accopiamento dei gruppi formati da tre moduli.
Last connecting operations of the units formed of three modules.

pareti verticali è di circa 18,5 cm. La stazza totale del pontile è pari a circa 1200 t. Una volta assemblata, la struttura assume la forma di un arco con lunghezza uguale a circa 120 m e concavità rivolta verso riva.
I moduli sono prefabbricati in stabilimento a Varese grazie all'impiego di un cassero metallico. Per il loro confezionamento è utilizzato calcestruzzo di classe C40/50 e acciaio B450C. La gabbia delle armature lente del singolo elemento è preassemblata a piè d'opera e quindi inserita nel cassero prima del getto del calcestruzzo. Segue il montaggio degli inserti necessari per il passaggio delle barre di preassemblaggio dei moduli e quelli per la formazione delle selle di appoggio e deviazione (diabolos) dei cavi di precompressione. Si procede quindi al getto simultaneo della soletta di fondo e delle quattro pareti verticali del modulo, seguito a distanza di 24 a 36 ore da quello di completamento della soletta superiore.
Gli elementi prefabbricati sono in seguito trasportati su strada sino

Product's geometry and design technique

The jetty consists of 20 prefabricated modules made of reinforced concrete, trapezoidal in shape with an average length of 5.6 m, a cross section of 4 m width and height of 3 m. The two pierhead modules differ in their arrangement and dimensions of internal structure from the other 18 in the central zone in that they are for housing the anchorage heads of the prestressed cables. The thickness of the bottom slab of the modules is 22 cm while that of the upper slab and vertical walls is about 18.5 cm. The total registered tonnage of the landing stage is about 1,200 tons. Once assembled the structure took on the shape of an arch with an average length of about 120 m and concavity in the direction of the bank.
The modules were manufactured in the plant at Varese thanks to the use of a steel formwork. Class C40/50 concrete and B450C steel were used. The frame for the concrete steel reinforcement of the single block was preassembled on

alla darsena di varo di Sant'Anna situata presso Sesto Calende. Qui avviene la messa in acqua (fig. 1) dei moduli e un primo assemblaggio a gruppi di tre. Questa operazione è effettuata utilizzando 8 barre Ø 40, f_{pk} = 1030 N/mm^2, disposte su ciascuna interfaccia di collegamento. In questa fase le barre vengono tesate ad un valore non superiore a 100 kN.
Successivamente viene realizzato il giunto di continuità fra moduli mediante iniezione di malta cementizia debolmente espansiva praticata nell'intercapedine creata dall'accostamento dei moduli e dall'interposizione fra di essi di un nastro di neoprene posto lungo il perimetro delle facce da accoppiare. Avvenuta la maturazione della malta di iniezione dei giunti, le barre sono tesate una seconda volta ad un valore limite uguale a circa 750 kN.
Ciascun gruppo formato da tre moduli è quindi trasportato via acqua dalla darsena di varo alla zona temporanea di ormeggio posta a circa 300 metri dalla riva. In questo luogo, al riparo da moti ondosi importanti (fig. 2), sono

Fig. 3
Il manufatto al luogo d'impianto definitivo.
The product at the place of final installation.

site and therefore inserted in the steel formwork before casting the concrete. Then followed the assembly of the inserts necessary to accommodate the preassembled module bars and those for the formation of the saddle and deviation supports (diabolos) for the prestressed cables. Next, simultaneous casting of the bottom slab and four vertical walls of the module took place, followed after 24 to 36 hours by that for completion of the upper slab.
The prefabricated items were then transported by road as far as the Sant'Anna dock slipway situated near Sesto Calende. Here the modules were placed in the water (Fig. 1) and assembled in groups of three. This operation was carried out using eight prestressing bars arranged on each connecting interface with Ø 40 and f_{pk} = 1,030 N/mm^2. In this phase the bars were tightened to a value of not more than 100 kN.
Subsequently, a continuity joint was created between modules by means of an injection of slightly expansive mortar, made in the cavity created by the line-up of

effettuate le ultime operazioni di accoppiamento dei gruppi precedentemente assemblati. Una volta completato il collegamento di tutti e 20 i moduli si procede alla messa in opera del sistema di precompressione costituito da 8 cavi postesi ciascuno formato da 12 trefoli di 0,6', f_{pk} = 1860 N/mm^2, e alla successiva messa in tensione dei cavi per una forza totale di precompressione misurata al martinetto pari a circa 18 750 kN.
Il manufatto finito completo dei flaps di stabilizzazione idrodinamica è quindi trasportato via lago al luogo d'impianto definitivo (fig. 3) dove sono in attesa le catene di ormeggio preventivamente messe in opera.

Sistema e tecnica di messa in precompressione

Lo stato di sollecitazione della struttura in oggetto è caratterizzato da variazioni cicliche che impongono l'utilizzo di una precompressione centrata con tensioni uniformi su ciascuna sezione trasversale del pontile. La tecnica di precompressione esterna qui adottata (con cavi che corrono

the modules and the insertion between them of a neoprene band, placed along the perimeter of the surfaces to be joined. When the mortar injected into the joints had hardened, the bars were tightened a second time to a limit value of about 750 kN.
Each group formed of three modules was then carried by water from the dock slipway to the temporary mooring zone located at about 300 metres from the bank. Here, sheltered from significant wave movement (Fig. 2), the last connecting operations of the units previously assembled were carried out. Once the connection of all 20 modules had been completed, setting up of the prestressed system took place, comprising 8 cables, each one formed of 12 strands of 0.6', f_{pk} = 1,860 N/mm^2 and subsequent tightening of the cables for a total prestressed force measured with a jack of about 18,750 kN.
The finished product, complete with hydrodynamic stabilizing flaps, was then carried by lake to the final place of installation (Fig. 3) where it awaited the mooring

Fig. 4
Impiego di due martinetti monotrefolo.
Use of two single strand jacks.

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chains which had been set up previously.

Prestressing system and technique

The state of stress of the structure in question is characterized by cyclical variations, which impose the use of prestressing centred with uniform tension on each cross section of the landing stage. The external prestressing technique adopted here (with cables that run in the internal free space of the modules), presents various advantages compared to other systems currently in use. The external alignment of the cables allows containment of the thickness of the slabs and walls of the module, which must satisfy, in this case, only static requirements and those concerning guaranteed minimum concrete cover to reinforcement.
The use of greased and PE sheathed strands located inside HDPE tubes, reduces the coefficient of friction to the minimum between these items and facilitates the stressing of cables 120 m long from one end. This makes it possible to carry out the stressing operations outside the head modules

nello spazio libero interno dei moduli) presenta diversi vantaggi rispetto ad altri sistemi correntemente utilizzati. L'andamento esterno dei cavi permette di contenere gli spessori delle solette e delle pareti del modulo che devono soddisfare, in questo caso, a sole esigenze statiche e di copriferro minimo garantito.
L'impiego di trefoli inguainati e lubrificati posti all'interno di tubi guaina PEHD, riduce al minimo il coefficiente di attrito fra tali elementi e consente la messa in tensione di cavi di lunghezza 120 m a partire da una sola estremità. Ciò rende possibile effettuare le operazioni di tesatura all'esterno dei moduli di testata grazie all'adozione di cavi ad andamento incrociato.
La tecnica utilizzata per il confezionamento dei cavi prevede che l'inserimento nel tubo guaina di ciascun trefolo inguainato e lubrificato avvenga in maniera indipendente dagli altri grazie all'utilizzo di un sistema di trascinamento a spola di filo che garantisce un perfetto allineamento dei trefoli che compongono lo stesso cavo. La successiva iniezione del tubo guaina con malta cementizia

Fig. 5
Impiego di un martinetto multitrefolo.
Use of a multi strand jack.

thanks to the use of cables in crossed alignment.
The technique used for making the cables provides for insertion in the HDPE tube of each strand to take place independently of the others thanks to the use of a netting needle drag system, which ensures perfect alignment of the strands comprising the cable. The subsequent injection of the cladding tube with slight expansion mortar guarantees the correct distance between strands, which can be tightened in this way, independently of each other ensuring greater actual flexibility and better tightening control.
Protection of each individual strand is ensured by a triple safety system formed by the external HDPE tube, the sheathing of the strand itself and the grease that surrounds it.
Another advantage of the chosen system is the possibility of making provision for additional lengths of strand required for assembly, thanks to which it will always be possible to adjust each individual item for the purpose of controlling tightening over time and possibly readjusting its value for dealing with loss due to creep in the concrete and steel relaxation.
The tightening work was perfected and completed by using two single strand jacks (Fig. 4) and one multi strand jack (Fig. 5).

debolmente espansiva garantisce il corretto distanziamento dei trefoli che possono così essere tesati in modo indipendente l'uno dall'altro garantendo maggior flessibilità esecutiva e un controllo migliore della tensione.
La protezione del singolo trefolo è assicurata da un triplice sistema di sicurezza formato dalla guaina esterna del tubo, da quella esterna del trefolo stesso e dal grasso che lo avvolge.
Altro vantaggio del sistema scelto è la possibilità di prevedere delle sovralunghezze di montaggio dei trefoli, grazie alle quali sarà sempre possibile agire sul singolo elemento al fine di controllarne la tensione nel tempo ed eventualmente riaggiustarne il valore per far fronte alle perdite per fluage del calcestruzzo e per rilassamento dell'acciaio.
Gli interventi di tesatura sono stati portati a termine mediante l'impiego di due martinetti monotrefolo (fig. 4) e di un martinetto multitrefolo (fig. 5).

Autori/Authors

Antonio Paronesso
Dott. ing. dipl. EPFL
AR&PA Engineering Sagl
CH-6963 Lugano-Pregassona
antonio.paronesso@arpa-engineering.ch

François Prongué
Ing. dipl. EPFL
Freyssinet SA
CH-1510 Moudon
prongue@bluewin.ch