Technical Report

ATKINS CHINA LIMITED

Review of the Use of Xypex Waterproofing Admixture and Concentrate for CC300 Tsuen Wan Station and Approach Tunnels

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Author(s)		**Job Number**
	P W Trinder	**100153**
Technical Approval	**W R Grace**	**Date**
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Abstract

Atkins China Limited has requested that TEL perform a review of submitted material relating to the use of Xypex admixtures for the CC300 Tsuen Wan Station and Approach Tunnels in Hong Kong. This report reviews the submitted material and other relevant documents, within the public domain, regarding the potential performance of Xypex as a waterproofing material.

Taywood Engineering Limited

Suite 2, 14 Brodie Hall Drive
Bentley Western Australia 6102
Post Office Box 1021
Bentley Delivery Centre Western Australia 6983

Telephone: : (08) 9470 1511
Facsimile : (08) 9470 1279

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1.0 INTRODUCTION

1.1 General

Atkins China Limited has instructed Taywood Engineering to conduct a review of material supplied in support of a request, by Penta-Ocean-Kier Joint Venture, to use Xypex products on the Tsuen Wan Station and Approach Tunnels. It is proposed that Xypex admixtures and concentrate are to be used as an alternative to waterproof membranes and cementitious reactive coatings respectively.

As stated in correspondence between Penta-Ocean –Kier Joint Venture, the principles of the proposal are to:

- Omit specified membrane and use XYPEX Admixture for the tunnel base slab, wall and roof slab.
- Omit specified cementitious reactive coating for the top of the tunnel base slab.
- Use XYPEX concentrate for the station/transition diaphragm wall
- Omit specified membrane and use XYPEX Admixture for the station track slab, ground floor slab, roof slab adit slab/wall

It is noted that the Particular Specification requires that any waterproof membrane is to be considered as a secondary protection mechanism. As it is proposed that Xypex materials be substituted for the membrane, it is anticipated that is to be similarly treated as a secondary protection measure.

1.2 Documents Reviewed

Atkins China Limited has supplied the following information as the basis for the review:

- Correspondence (Ref CC300/CN117/WRICRC2000-0130999) from KCR West Rail Division to Construction Engineering Manager
- Correspondence (Ref CC300/000648/CN117) from Penta-Ocean-Kier Joint Venture to Atkins China Limited
- Extracts from drawings outlining the location of Xypex usage

- Final Durability Assessment Report West Rail DD-300 Tsuen Wan Section Milestone 4-9 Car Scheme

In addition the following information, obtained from the public domain has been reviewed:

- Report by Mahaffey and Associates on Chloride Ion Penetration into Concrete containing XYPEX
- Expert Opinion RE Concrete Sealant Material (XYPEX) by State-Licensed Research Institute for Silicate Technology
- Bautest Laboratories for Preparation and Methodology
- Paper entitled An Enhancement in the Nature of Concrete with a Multiplicative Cement Crystal Type Concrete Material by Mitsuki et al
- XYPEX produced project profiles
- Selected structural drawings

In addition the following additional information previously provided to Taywood Engineering by the material supplier has been considered:

- XYPEX Australia – An Introduction to XYPEX Waterproofing by Crystallization
- XYPEX Australia – Xypex prevents Ingress of Chlorides and Protects Steel reinforcement from corrosion

In addition to the above reference is made to independent testing conducted by Taywood Engineering Limited on the Sulphate resistance, chloride diffusion characteristics and water permeability of various cement types and chemical admixtures.

1.3 Basis of Review

This review has been based on the assumption that all relevant requirements of the MS4 DAR and the West Rail Particular Specifications (as amended in Appendix Q of MS4 DAR) are maintained.

2.0 FINDINGS OF REVIEW

Atkins China Ltd have requested that TEL conduct a review of information supplied by them to review a proposal to use Xypex Admixtures and Concentrate as an alternative to the specified waterproof membrane and cementitious reactive coating. In addition TEL has obtained supporting information from reports and data sheets contained within their library and other readily available sources of publicly available material. The review of this information has found that, provided all other conditions of the MS4 DAR and particular specification at maintained, the durability of the tunnel will not be detrimentally affected by the substitution of Xypex admixture and concentrate for the specified waterproof membranes.

3.0 DESCRIPTION

3.1 Construction Methods

According to the MS4 DAR the Tsuen Wan Section of West Rail is constructed in an area of reclamation. Generally, the station box is formed with permanent diaphragm walls and constructed using a bottom up method. All internal slab and walls are formed in reinforced concrete and the station is founded on bored piles. The approach tunnels have a transition zone at either end of the station, constructed in a top down method, with the remainder constructed bottom-up using temporary diaphragm walls to support the excavation

POKJV has proposed the use of Xypex concrete waterproofing materials as an alternative to the use of waterproof membranes. The mechanism by which Xypex is reported to achieve waterproof concrete is described in subsequent sections of this report.

3.2 Environment

Ove Arup and Partners have conducted a detailed review of the environment in their report entitled- KCRC DD300 Tsuen Wan Station- Review of Groundwater and Soil Test Results. This report was based on chemical tests on groundwater samples and soil samples from boreholes on the site of the Tsuen Wan Station, supplied by Atkins China Limited.

This review found that, with the exception of the risk of chloride induced reinforcement corrosion, the performance of PVC, rubber or cementitious materials should not be significantly affected by the existent soil and groundwater conditions.

As the Xypex crystals are formed within the cementitious matrix it is furthermore expected that this environment to which it is exposed will not affect its performance.

3.3 XYPEX Application

Based on information provided for review it is understood that it is proposed to use Xypex admixtures and concentrates in the following locations:

Station Box

Xypex admixture to concrete for floor and roof slabs

Xypex admixture to concrete capping beam on Grid G

Xypex concentrate to diaphragm walls

Areas with temporary Diaphragm Walls

No treatment to diaphragm walls

Xypex admixture to concrete for tunnel lining

Areas with permanent Diaphragm Walls

Xypex Concentrate to Diaphragm walls

Xypex admixture to concrete for roof and floor concrete

3.4 Assumptions upon which the review is based

The following assumptions have been made while conducting this assessment:

- All other performance requirements, including concrete strength, cement contents and chloride diffusion requirements as specified in Table 2 **–Target Durability Requirements –** in the MS4 DAR will be maintained.
- Crack width limits as stated in Table A6 of Appendix A of MS4 DAR will be maintained
- PFA will be used in all mixes
- Concrete shrinkage limits will be maintained and transverse reinforcement will be maintained at levels that are sufficient to control expected shrinkage
- Waterproof joints between Diaphragm wall panels will be ensured
- Waterstops will be provided to all joints in accordance with the requirements of the MS4 DAR.

4.0 XYPEX AS A WATERPROOFING ADDITIVE

4.1 Method of Treatment

According to the manufacturer the incorporation of Xypex into concrete leads to the development of 'waterproof concrete' by the creation of *non-soluble quartz like crystal which grows in the bleed tracts and capillaries forming within the concrete.* For new construction Xypex is normally added as a concrete admixture at the batch plant (typically at a dose rate of 0.8 to 0.9% by weight of cement). This results in the formation of the *non-soluble quartz like crystal* structure throughout the full thickness of the element being treated.

For thick or existing sections such as the permanent diaphragm walls, surface treatment by concentrates are proposed as an alternative to cementitious reactive coatings. In such situations Xypex is applied to the surfaces rather than the full thickness of the element being treated. The reactive chemicals are then absorbed into the bulk of the concrete resulting in the formation of a surface layer impregnated with the Xypex generated crystal structure. The depth of the impregnated layer is dependent on the rate of absorption and reaction of the active component of the Xypex.

Experimental evidence confirming that crystals will propagate from the surface into the bulk of fresh concrete is provided by the work of Yasuo Mitsuki (1). In this work penetration rates of over 30 cm per year were recorded.

4.2 Mechanism of Crystal Formation

The long-term performance of the Xypex admixtures and surface treatments depends largely on the crystalline structure created by the reaction of the admixture with the products of cement hydration. Unfortunately as there is limited published information on the composition of the material it is not possible to fully describe the crystalline form of the material.

Some indication of the likely performance of Xypex can be derived by studying information provided by the supplier. The structure they describe can be compared to that formed by normal cement hydration which can be summarised by the following equations:

- Tricalcium Silicate Reaction $2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$
- Dicalcium Silicate $2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2$
- Tricalcium Aluminate $C_3A + 6H \rightarrow C_3AH_6$

The Xypex material contains a mixture of Portland Cement, silica sand and unspecified inorganic chemical complexes. According to Xypex literature this mixture reacts with water to produce calcium carbonate and water soluble silicate (Information on the chemical composition of the reactive components is not available from either the Australian manufacturer or the Canadian licensor). Assurance has however been given that the water soluble silica is not a sodium silicate and therefore does not suffer from the difficulties associated with admixtures containing such materials.

The silicate reacts with calcium hydroxide (produced by the cement hydration process) to form a calcium silicate hydrate C-S-H similar to that formed by cement hydration but with a variable hydrate concentration (CSH_n).

The following extract from a Xypex Australia document entitled Crystalline Barriers describes the mechanism of crystal growth resulting from the application of Xypex to concrete:

> "*During the cement hydration process, the crystalline complex reacts with calcium hydroxide and various metal oxides and salts found in the concrete. As a result of these reactions soluble connections or more complex salts capable of binding varying amounts of water are formed.*
>
> *Due to the consumption of calcium hydroxide the hydration of the cement will extend further than normal. Normally in setting concrete up to 25 per cent of the cement will not become hydrated due to the protection against water which the surrounding tobermorite gel offers. The reason for this is that the cement gel is changed in character. Due to an increase in volume the gel will craze which again*

allows the entry of more water to the unhydrated cement. This process produces still larger volumes of cement gel, and thus larger capillary tracks will be narrowed or possibly blocked to the passage of water.

Described as re-activated cement it is considered as spherical shell-like crystals due to the large number of polar groups. For stereometrical reasons these crystals have a positive charge on the outside and a negative charge towards the centre. Due to their size, water molecules may force their way into these shells and will there as a result of the negative charges (normally produced by oxygen atoms) be bound to these charges with weak hydrogen linkages (Van do Waal bonds). As the distance between the free positive negative charges increases, the crystals will outwardly become more positive, and the water molecules can now be bound to the outer surfaces of the shells because of the large dipole moment of the water and in this way the volume of the crystals will increase considerably."

Any unreacted admixture will lie dormant until water reaches it. On contact with future penetrating water it will react and block the pore opening to prevent further water penetration. This mechanism provides a capacity for some level of healing to cracks forming at later age.

5.0 GENERAL ISSUES RELATING TO POTENTIAL PERFORMANCE

5.1 Are There Any Concrete Admixtures That May Be Incompatible With Xypex?

Xypex admixtures have been used in premix concrete batch plants for a number of years and in a variety of applications and environments. According to information made available by the material supplier there have been no reported cases of incompatibility with pozzolans or admixtures. However, it has been found in some instances that the addition of Xypex may lead to retarded initial set. As a consequence if the use of set retarders is required the tendency for delayed set should be assessed by site trials prior to placement.

It is also noted that part of the Xypex reaction involves a reaction between the admixture and calcium hydroxide produced by the hydration of cement. As the concrete mix currently proposed for this structure has a high PFA content the calcium hydroxide content will be reduced. However, as the total cementitious content is high the proposed mix will contain 325kg of OPC cement per m^3, it is believed that this level of cement content combined with other reaction sites within the cementitious matrix will provide adequate levels of calcium hydroxide for the reaction to occur.

Along a similar vein consideration has been given to the effect of Xypex treatments on subsequent surface treatments. Where Xypex Concentrate is applied to walls the bond between the Xypex treatment and wall concrete will be dependent on the workmanship employed in its placement. If considered necessary poorly bonded or excess coating can be removed prior to the application of any subsequent surface coating.

5.2 Potential for AAR Reactivity

A further consideration could be the effect of Xypex on the potential for Alkali Aggregate Reactivity. Although the Xypex admixture and surface coating material has a high sodium oxide equivalent it has such a small dose rate (0.9% by weight of cement) that its overall effect on total sodium oxide equivalence is minimal. It is therefore not considered to have a significant effect on Alkali Aggregate Reactivity.

5.3 Long term Stability of the Xypex Crystal Structure

The crystal structure formed by the Xypex material is similar in form to that produced during hydration of Portland Cement. The material should therefore be as stable as the cement matrix in which it is bound. Furthermore by restricting the penetration of water the rate of penetration of aggressive agents will be reduced and the life of the material increased.

Effect of Sulphates

Soil testing has shown that certain locations within the construction area exhibit slightly elevated sulphate levels. Independent testing conducted recently by the Perth Office of TEL has shown that Xypex treated concrete has a high resistance to sulphate attack (2). It is therefore considered unlikely that significant attack from this mechanism would be experienced during the life of the structure.

Effect of Chlorides

Chloride penetration testing conducted by Mahaffey Associates (3) and others (4) have shown that treatment of concrete with Xypex (admixture rather than surface treatment) reduces the rate of chloride diffusion when compared to a control mix. Other testing performed independently, by TEL, has shown that some minor reduction in rates of chloride diffusion is obtained when Xypex is used as an admixture with OPC cements.

As the nominated concrete mix design contains 500kg of cementitious material including PFA its chloride diffusion coefficient would be expected to be extremely low and any improvement in the concrete’s performance against chloride diffusion will be moderate.

Effect of Cracking

MS4 of the relevant DAR places controls on the permissible crack widths to 0.25mm. The capacity of the Xypex additive to seal cracks of this width is therefore of critical significance. It is reported that the Xypex crystals are able to grow to fill and block static cracks up to 0.4mm. They are however unable to seal moving cracks. The materials successful use in the sealing of cracks has been reported for the Sydney Harbour Tunnel (Australia) and Marine and Harbours SA (Australia).

Effect of Bacterial attack

Sulphate Reducing Bacteria (SRB) are known to attack steel but concrete is generally immune from bacterial attack unless Sulphate Oxidising Bacteria (SOB) are present. Therefore provided the concrete is sufficiently impervious to restrict access of water borne SRB to the reinforcement there will be no concern for this form of attack

If SOBs are present they will oxidise any hydrogen sulphide in the environment to sulphuric acid. In the unlikely event of this occurring the acid formed may attack the cement matrix. There is insufficient evidence to predict the rate and severity of any such attack but the soil analysis conducted to date does tend to indicate that SOBs are not present.

5.4 Potential for Crystal Growth to Result in Concrete Spalling

Xypex forms needle shaped calcium silicate hydrate crystals similar to those formed by the cement hydration process. According to information provided by the material supplier these crystals will grow (in the presence of required constituents) to fill any pore space, voids or cracks. Unlike ettringite, which is a calcium sulphoaluminate hydrate, crystal growth is limited by the space available for formation. Consequently they are not to expected generate a large expansive force.

6.0 PERFORMANCE OF XYPEX COMPARED TO SPECIFIED MATERIAL

6.1 Xypex Concentrate as an Alternative to Cementitious Reactive Coatings

Xypex concentrate is generically similar to other products such as Vandex. This family of materials all form a calcium-silicate-hydrate crystal structure within the cement matrix and as such can be considered to be cementitious reactive coatings. The use of Xypex concentrate is therefore not considered to constitute a variation from the specification.

6.2 Xypex Admixture as an Alternative to Waterproof Membranes

6.2.1 <u>Effectiveness of Waterproof Membranes</u>

The West Rail Design Criteria requires that the design of all below ground structures consider any waterproof membrane to act as a secondary protection measure. The primary protection measure being the production of high quality concrete with high durability, low permeability and cracking of not more than 0.2mm in width.

The relevant MS4 DAR also recognises that failures in waterproof membranes are common and that failures in membranes may lead to water leakage through cracks and joints. Detailed instructions for the repair of such defects have been included as an addition to the Particular Specification (Addition to Clause 22.22.01 and 22.23.01 as noted in Appendix Q of MS4 DAR).

Failures to waterproof membranes generally occur as a result of poor detailing, cuts in the membrane during construction or failed joints between membrane sheets. Commonly such defects are not identified until after placement of the concrete and the cessation of dewatering activities.

Any water that bypasses the membrane will travel (under pressure) along the interface between the membrane and concrete and will penetrate through cracks and joints in the concrete. Therefore the site of eventual observable water leakage may be some distance from the actual point of membrane failure.

6.3 Xypex as a Waterproofing Additive

There is a significant amount of evidence to show that Xypex will effectively waterproof bulk concrete (5 & 6). The ability of Xypex admixtures to reduce water permeability has also been confirmed by unpublished independent research performed by TEL. The capacity of Xypex admixture to seal moderate sized static cracks has also been well documented.

Therefore, provided cracking can be controlled, water penetration through Xypex treated concrete should be prevented. Water penetration through joints and large cracks may however still occur.

6.4 Treatment of Joints

The proposal under review includes the use of Xypex concentrate to concrete surfaces forming joints between walls and slabs and slab construction joints. The application of the concentrate being in addition to specified details will lead to an increased certainty of achieving a watertight joint.

6.5 Treatment of Major Cracks

There is currently debate within the international engineering community regarding the capacity of crystal growth waterproof admixtures to seal major cracks of width greater than 0.2 to 0.25mm. However, as the MS4 DAR requires all such cracks be repaired there is no need for such a level of crack sealing by the admixture.

6.6 Long Term Performance of the Waterproofing Procedure

As the waterproof admixture and concentrate develop inert crystal structures within the cementitious matrix they will have equal or greater life that the concrete itself. Additionally, testing conducted by TEL on sulphate exposure tend to indicate that in these types of environment the addition of crystal growth admixtures will increase the durability of the parent concrete.

As the tunnels will be in a generally constant and stable environment and not subjected to cyclic loads, significant to their dead loads there will be little or no opening or closing of joints and cracks. The static nature of these joints and cracks increases the confidence in the capacity of the proposed alternative to provide long term performance.

6.7 Effect of Xypex on Long-term durability

The particular specification requires that any sites of water penetration are repaired prior to the completion of construction. Therefore, irrespective of the method chosen, the contractor is responsible for ensuring that all water leakage is stopped prior to the completion of the works. Provided the requirements of the MS4 DAR are met the completed tunnel will be free of leaks.

The MS4 DAR has identified that the greatest risk of long term deterioration is the corrosion of internal reinforcement due to the back diffusion of chlorides from the inner surface where water leakage is allowed to develop. There is evidence from testing conducted by a number of organisations to show that the addition of Xypex will reduce the rate of penetration of chlorides through concrete. It can therefore be argued that the addition of Xypex (both as admixture or concentrate) may actually increase the long term durability of the concrete elements

REFERENCES

1 An Enhancement In The Nature of Concrete With A Multiplicative Cement Crystal Type Concrete Material, Yasuo Mitsuki Et Al, 46th Annual Meeting of The Civil Engineering Society (Sep 1992)

2 Resistance of Concrete To Harsh Environments, Trinder Et Al, Concrete In Australia, (1999)

3 Chloride Ion Penetration Into Concrete Containing Xypex, Mahaffey Associates Pty Ltd (1996).

4 Rapid Chloride Ion Penetration Test Report, Queensland University of Technology (1997)

5 Evaluation of Xypex crystalline products to block pores and seal cracks, James Neill & Associates Ltd. 1998

6 Crack Sealing Crack Healing Capacity of Xypex, Setco Singapore