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Rehabilitation of Sewers with an Alternative Material

Rénovation des égouts avec un matériau de rechange

Erneuerung von Abwasserkanälen mit Alternativbaustoffen

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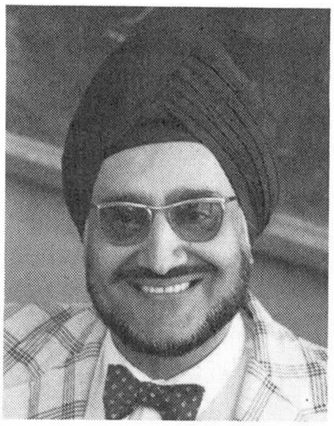

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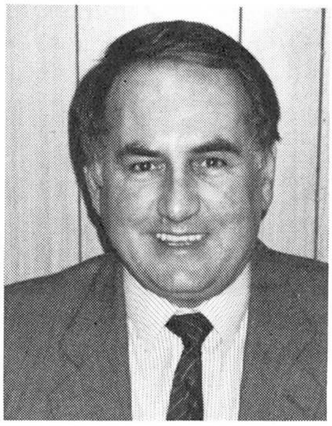

SUMMARY
The magnitude of the task of rehabilitation calls for critical assessment of the existing materials and for development of efficient alternatives. Such a development, using ferrocement, has led to the production of specifications and design procedures for a "mixed" structure. This is now accepted as an "established system" and has been found to be cost-effective and adaptable for use in sewers with variations in alignment and cross-section.

RÉSUMÉ
L'importance de la tâche de rénovation demande une évaluation critique des matériaux existants et le développement d'autres solutions efficaces. Le développement de la technique, utilisant le ferrociment, a conduit à l'élaboration de directives et de procédés de calculs prônant une structure mixte. Cette dernière est actuellement considérée comme un système établi, jugé rentable financièrement, et dont l'emploi est adaptable aux égouts après transformations de l'alignement et de la section.

ZUSAMMENFASSUNG
Die Wichtigkeit der Erneuerung erfordert sowohl eine kritische Beurteilung der vorhandenen Baustoffe als auch die Entwicklung von neuen effizienten Lösungen. Eine derartige Entwicklung unter Verwendung von Ferrozement hat zu Spezifikationen und Bemessungsregeln für ein Mischsystem geführt. Das System hat sich etabliert und führt zu anpassungsfähigen kostengünstigen Lösungen für Abwasserkanäle mit variablem Querschnitt.

1. INTRODUCTION

Needs for maintenance and rehabilitation of infrastructures are drawing a rapidly increasing proportion of finances available to the civil engineering industry. As far as the countries with old sewerage systems are concerned, most of the expenditure on sewers is incurred in improving their structural performance and the capacity of the existing networks. When structural improvement is sought through relining it is important that the impairment to the sewer capacity is minimal. The magnitude of the task of rehabilitation is indicated by, for example, Schrock [1] who estimated that, in 1984, in the USA alone there were about half a million sewer collapses and stoppages and that 75% of the sewers were performing at a 50% capacity or less. A great majority of sewers are brick or stone walled and the estimates of the funds required to keep them operational are vast. It is, therefore, necessary to assess all the old and new alternative materials and methods of rehabilitation carefully so that optimal choices can be made. Up to 1984 the methods for man-entry sewers were restricted to the use of preformed glass reinforced cement/plastic, high density polyethylene and Gunite, the last sometimes carried out in-situ for sewer size of 1500 mm or larger. The authors experienced a number of construction and design problems with the existing methods which have adverse effects on the performance and the cost [2]. For example, existing access shafts had to be renewed, substantial reductions in capacity had to be tolerated, extensive internal and external (e.g. traffic) disruptions had to be tolerated, and Gunite produced rebound problems which had to be paid for. To overcome these it was decided to seek an alternative material and method/process that would be suitable for precast and in situ work. Ferrocement was identified as the most suitable material and the wet spraying method was chosen as the appropriate process for construction. A "mixed structure" resulted from bonding the rehabilitation layer to the old masonry wall. The system developed has proved to be particularly adaptable for use in sewers with variations in alignment and cross-section.

2. FERROCEMENT

Credit for inventing (in 1847) reinforced concrete is often given to Lambot. His description of the then "new" material would today be recognised as "ferrocement". This distinct identity was given to it by Nervi a hundred years later so as to emphasise its distinct characteristics as compared to what is now called reinforced concrete. Figures 1 and 2 compare this material with Gunite and reinforced concrete respectively. It is obvious that ferrocement possesses ductility and toughness combined with excellent control on crack widths. This highly versatile material can be formed into thin sections in which fine wire meshes (or nets or expanded metal) act as reinforcement in Portland cement and sand mortar. Mortar cover of 3 to 7 mm thickness has been found to be adequate even in corrosive environments over many decades. The superior characteristics of ferrocement arise from the high passivity of the cement-rich mortar of very low permeability and from the high cover-thickness to wire-diameter ratio, as well as from the fact that the preferentially oriented meshes, made from closely spaced fine wires, provide an excellent crack control mechanism. The catalogues of examples of successful applications of the composite are very impressive [3].

3. BACKGROUND TO RESEARCH AND DEVELOPMENT

Various detailed studies [e.g. 4] pointed to the necessity of phenomenological investigations in the laboratory and the field. These formed part of the work undertaken by the authors, on the one hand, and the Water Research Engineering

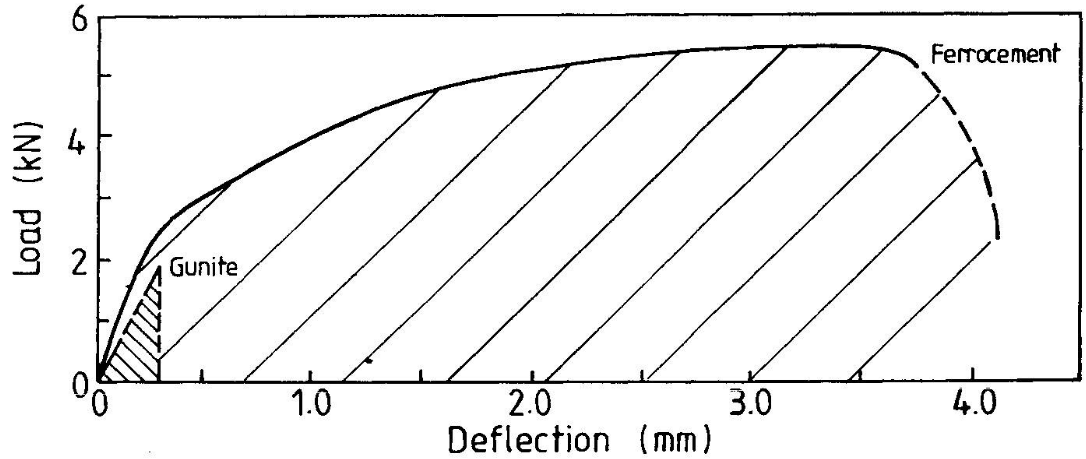

Figure 1 Load-deflection behaviour of ferrocement compared with that of Gunite

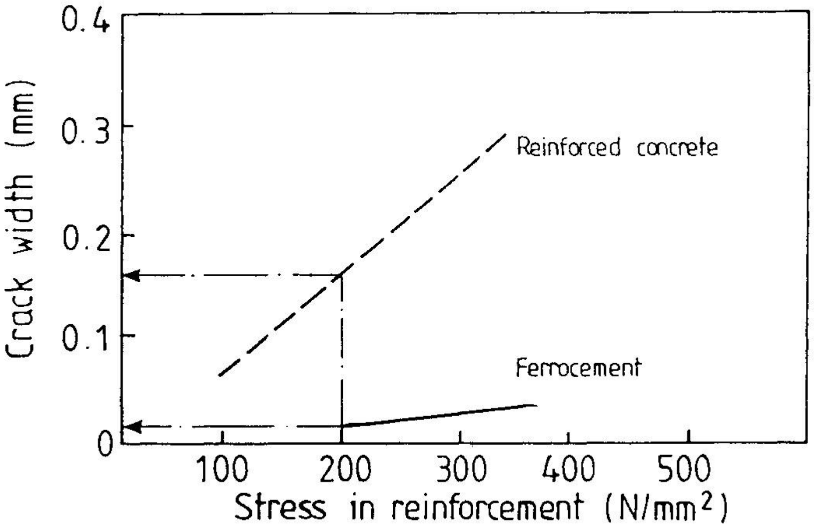

Figure 2 Flexural crack - steel stress behaviour of ferrocement compared with that of reinforced concrete

Centre (WRc UK) on the other. The latter carried out trials with the Department of the Environment to research and assess the various developing renovation systems.

In view of the importance of the durability requirements special attention was paid to the long term monotonic and fatigue strength and abrasive resistance. So as to enhance the nature and reliability of the test results, it was decided to compare the new system with Gunite (shotcrete) which is already an established and accepted method for sewer renovation [5]. The long term tests involved subjecting the specimens to accelerated corrosive environment and to concurrent sustained preload which was equivalent to 200 N/mm^2 stress in the outer layer of the meshes. All the results demonstrated that ferrocement is superior to Gunite. For example, the abrasion resistance of ferrocement was found to be about six times and the long term flexural strength was not only greater than that of Gunite but it showed no sign of deterioration despite the fact that the ferrocement specimens had cracks under the sustained load and that the cover was only 5 mm thick.

A number of on-site trials were conducted to assess the various practical aspects of "constructability" and effectiveness of in situ coatings and precast linings. These trials proved to be very successful. The high density of the material and its bond to the existing structures were confirmed by core testing. This programme was completed in 1987 by which time about 2200 lin m of sewers, ranging in size from 900 x 600 mm to 1900 x 1200 mm, were rehabilitated. These trials were required by the WRc for formal acceptance of the Ferro-Monk System as an "established system". Subsequently, more than twenty five contracts have been successfully completed by Monk, including one in Brussels.

Cost savings have been experienced by clients and where tenders have included realistic annulus grout figures or have simply asked for a fixed price all-in rate, savings of up to 30% have been experienced in direct comparison with all other structural man-entry rehabilitation systems. This saving and about 33% saving in cross-sectional areas have fully justified the development of the sprayed system.

The above noted work has led to the drawing up of specifications and design procedures, in conjunction with the WRc.

4. DESIGN OF THE MIXED SEWER STRUCTURE

4.1 Design Criteria

The two primary criteria for the design of a ferrocement rehabilitation layer are:

1. The stress in the reinforcement should not be allowed to exceed 200 N/mm^2.

2. The surface track width should not be more than 0.04 mm.

As will be seen later, in this mixed structure the rehabilitation layer is assumed to be in tension. The whole of the tension is assumed to be taken by the reinforcement. Calculation of the steel stress is therefore a simple task. The second criterion addresses the problem of the effects of corrosive environment. Results of a number of studies show that the crack width should be limited to about 0.05 mm. Unfortunately, the crack widths cannot be predicted with an acceptable degree of reliability [4, 6]. For example, the predicted value of maximum crack width can range from 0.01 to .03 mm (for a particular case) depending on the prediction model used. Because of the inadequacies of all the published modes, physical testing of this composite material is imperative. The authors' view supports that taken by the WRc, which seeks assessment of this material through "TypeTesting".

Fortunately, because of the excellent crack arresting mechanism inherent in ferrocement the criterion of steel stress is violated at a load which is considerably lower than that required to produce a maximum crack width of 0.05 mm. Therefore, the design has to be based on the steel stress criterion which is reliably catered for.

4.2 Design Procedures for Coatings and Linings

The WRc [5] recommends that the design should consider structural integrity, material deterioration and hydraulic capacity. The structural design procedure (for Type 1) is described below, briefly:

Type 1 rehabilitation [7] utilises structural capacity of the existing sewer and requires full bond at the interface with the existing masonry. The design procedure calls for two checks.

When precast linings are used the annulus space has to be filled with grout which provides the bond between the new and the old components. During grouting, deformation and buckling are the two risks that have to be avoided. The WRc manual facilitates (through charts) determination of the maximum allowable external pressure. The procedure is simple in which the input information is the geometry and the short term loading strength of the material. This check is referred to as a short term check.

The second check is referred to as long term. The purpose of the ferrocement layer is to provide a tensile capacity particularly at the crown of the sewer which is assumed to experience maximum bending moment. Figure 3 depicts the mixed action of the existing sewer wall and the coating/lining at the crown. Figure 4 gives the design procedure. The design parameters are:

a. Long term vertical pressure from soil and surcharge, P N/mm^2
b. Crown bending moment coefficient, C (dependent on soil conditions)
c. Mean width of existing sewer, d mm
d. Existing wall thickness, t_2 mm
e. Grout thickness (for lining), t_1 mm: 25 mm minimum
f. Rear cover (for coating), t_1 mm: 10 mm minimum
g. Trial thickness, t mm
h. Working tensile strength of mesh, s N/mm^2 : based on tests
i. Factor of safety, F: minimum 1.25

The calculation of the lever arm t_d is done as follows:

Lining: $t_d = 0.67t_2 + t_1 + 0.5t$

Coating: $t_d = 0.67t_2 + t_1 + 0.5(t - t_1)$

The crown bending moment, M per unit length of the sewer is obtained, simply, from the expression $CPd^2/4$.

5. CONCLUSIONS

The newly developed mixed system incorporating ferrocement overcomes many of the problems associated with the existing method of rehabilitation of man-entry sewers. Material specifications and design procedures have been subjected to on-site and laboratory trials, the success of which has led to the acceptance of the new system as an "established system". It has proved to be not only a cost-effective system but also to be the one which causes minimal amount of capacity impairment. It can be used, at present, in all the environments in which Portland cement compositions are acceptable.

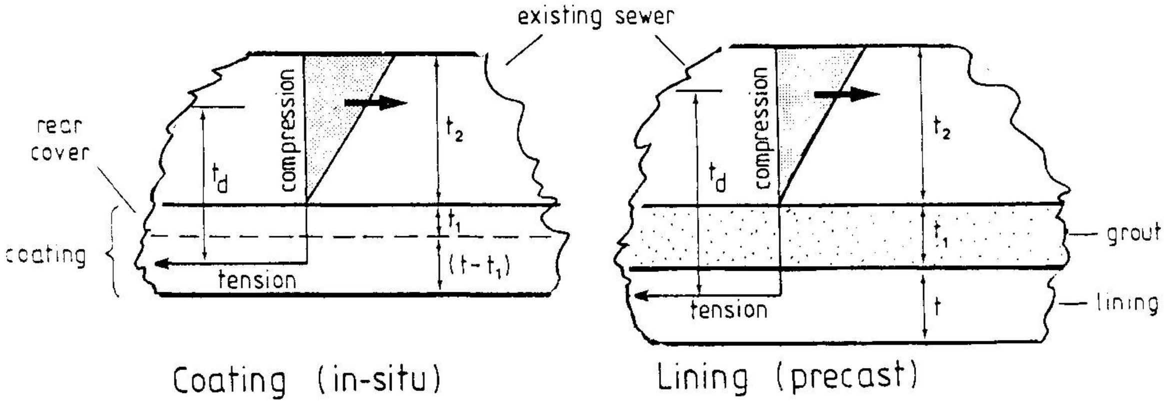

Figure 3 Assumed composite action in flexure (WRc)

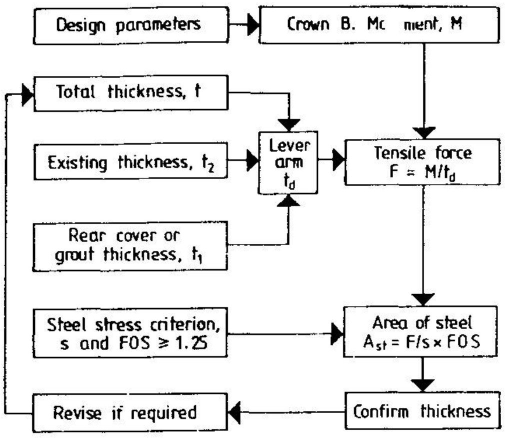

Figure 4 Design procedure

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