Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 14 (1992)

Artikel: Repair and maintenance

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DOI: https://doi.org/10.5169/seals-853273

REPAIR AND MAINTENANCE

by

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1. INTRODUCTION

Durability becomes one of the most important factors in planning, design, construction and maintenance of structures. It is established that construction materials, load levels, and environmental conditions govern the service life of structures. The most common construction materials such as concrete and steel may be considered inherently durable ones, if properly designed for the enviroment and carefully produced or fabricated with good quality. However, concrete is potentially vulnerable to be attacked under different exposures unless certain precautions are taken. Deterioration of concrete structures at manifest condition is more inducive to further damage, which may render its unsuitable for futher use. Even economic and political consideration may be important in decision on maintenance and repair, preventive maintenance will play the major role in controlling durability of structures.

In general, early attention to seal the cracks and restoration of water-proof joints may eliminate the need for costly repairs. The durability performance and service life relationship as shown in Fig.1, can be extended by periodic inspection, proper maintenance and repairs. In the case where more extensive deterioration has already occured, or earlier measures have not controlled a potential problem, an investigation should be made to determine the cause and steps taken to counteract the situation during the repair operations.

This paper has introduced inspection procedure, testing and monitoring methods, repair materials and techniques. Examples of repair cases for a chimney, bridge and building have been presented in accordance with their deterioration, structural evaluation and repair techniques.

2. INSPECTION WORK

Durability problems with part of the existing structures have emphasized the need to follow a rational operation and maintenance strategy in the upkeep of structures. If the problems have grown to levels where the traditional approach of repairing damaged structures, attempting them back to initial quaility will be exorbitantly expensive. New ways of handling such problems on both structural level and safety and reliability level have been sought. In the intermediate with unclear maintenance and repair strategies, size of the problems has been getting worse, especially problems concerning concrete structures, because major parts of concrete problems are rather new and the number of concrete structures is rather large.

Regular and systematic inspection shall be performed in order to identify and quantify possible ongoing deteriorations. Inspection constitutes an integral part of structural safety and serviceability by providing a link between the environmental condition to which the structure is subjected and the manner in which it performs with time. In an advanced form the general strategy toward durability should incorporate systematic inspection routines for structures in services, including automatic data recording and handling dicision models based on forcasting rate of degradations, and economic consequences of either short-term or long-term remedial measures. To arrive at comparable figures of alternative solutions, present-day value of the future costs for maintenance, repair and eventually demolition and rebuilding, must be sought.

Rational decision models applying modern probabilistic methods including safety policy and economics, are indispensable elements of an in-depth going appraisal. The element of investigation may in general contain the following items:

- Perform visual inspection.
- Check of original design : drawings, calculations.
- Check execution data : technical, non-technical, quality statement, inspection record.
- Perform in-situ testing : non-destructive, destructive, sampling.
- Perform laboratory testing : mechanical, physical, chemical.
- Perform recalculation.

Based hereon dicisions regarding safety precaution, repair, strengthening/upgrading, demolition and prevention of occurrance, must be made. Check list as provided in Table 1 has been established by RILEM and recommended by CEB (1) for investigation of deteriorated concrete.

3. TESTS AND MONITORING

The traditional testing of concrete at 28 days is a simple and operation means of verifying the strength requirements. With the growing concern for durability characteristics of concrete, much more involved testing is required in order to clarify if a concrete will be durable in a structure exposed to certain aggressive environments.

The tests and monitoring must concentrate on enviromental aggressivity, concrete quality, structural detailing, loading condition, crack sizes and surface condition. Test methods as shown in Tables 2 to 5 are for strength evalution, void location, water penetration, and chemical analyses as part of concrete and Table 6 is for evaluation of reinforcement condition and location as part of reinforcing steel.

In-situ load testing may be required to determine the performance of a structural element under loading greater than the working loads. A load test may be undertaken either to overcome the doubt concerning the quality of construction or design or to establish the behavior of a complete structures after services. Sophisticated analysis techniques can be calibrated using load tests. Where the test is undertaken to demonstrate that the structure behaves satisfactorily under load, it will be generally sufficient to measure the deflection. These must be shown to remain within acceptable limits, correlate with predicted values and recover substantially on unloading.

Long-term monitoring of a structures over a period of time can be used both to check on the safe working of the structures and also to provide information on its response to load or under service condition. When a structure is progressively deteriorating, long-term monitoring can be used to indicate when replacement or repair become necessary. Unlike load testing, this form of evaluation relies on loads occurring during the normal use of the structure. The loads that are imposed must be quantified to enable the structural adequacy to be determined. Due to the duration over which measurements are taken, the instrumentation must have good long-term stability. Movements in particular may need to be related to a reliable fixed datum and possibly also to second independent measuring system. Allowance must be made for the effects of daily or seasonal changes in temperature or humidity, and these must be separated from the permanent movements such as increases in crack widths.

4. REPAIR TECHNIQUES AND MATERIALS

Materials

Modern technology has made available many kinds of materials for repair and maintenance of concrete. These range from low-viscosity polymers for the sealing of very fine cracks, very rapid setting cements for repairs in the presence of flowing or seeping water, special concrete for overlays, to portland cement motar and concrete itself. As summerized in Table 7, it can be a guide for selecting repair materials to suit crack sizes and application techniques. The engineer will be faced with an array of potential materials to choose from, requiring a special knowledge for proper evaluation. A final selection will depend on many factors, such as properties during repair, mechanical reponse, long-term durability, cost index and prior field experience.

In repair, all damaged materials must be removed until a sound surface is reached, then cavity should be prepared to ensure good bonding between the concrete and the repair materials and to ensure proper consolidation. Measures should be taken to remove aggressive materials or to prevent their re-entry. It should be emphazied that all major causes of damages or deterioration must be properly taken care of for satisfactory condition prior to the execution of repair work.

Repair materials must be adjusted to conformed the properties as required for specific strength or durability as structural performance. Material testing must be conducted to satisfy the condition before usage.

Techniques

Injection - This technique has been successfully applied to very fine cracks as small as 0.05 mm with low viscosity polymeric grout. Such materials should be capable of forming a solid polymer in situ after injection. Epoxies are a popular choice, and many proprietary formulations are commercially available. The epoxy is injected under pressure in order to penetrate the very fine and to tortuous crack pattern that may exist. The success of pressure grouting depends on proper application to ensure that all cracks are sealed. The grouting can restore structural integrity as well as seal cracks against seepage.

Grouting - The grouting method is normally applied for larger cracks or joints. Cementetious mortars and caulking materials are general used. For durable and successful seal, the crack should be cleaned out and cut back to form a V-shaped groove into which the sealant can be well compacted. For deeper cracks and narrow cavities, pressure grout many be required. A good-quality portland cement mortar is satisfactory for larger cracks. In the presence of moisture, quick-setting admixtures should be used. For finer openings under dry conditions, caulks and putties based on organic polymers can be used. Sealants are of many types and properties; the selection should depend on considerations of anticipated service conditions, such as applied loads, condition of exposure, and the like. Once cracks and joints are repaired, a general protective coating is both beneficial and aesthetic.

Patching - This may involve filling of tie holes, bolt holes, prestressing ducts spaled holes, and so on. The simplest approach is to use dry-pack mortar for shallow hole and conventional replacement mortar for deeper cavities or for filling around rebars. If the area is so large, then shotcrete techniques may be used for some applications. Mortar should be as dry as possible, consistent with good compaction and pumpability. The use of admixtures to improve flow characteristic and to avoid shrinkage on subsequent drying may be advisable where the creation and maintenance of a good bond is important. All unsound, unbonded concrete should be removed, since a good bond is required between the old concrete and patching material. A mechanical bond by roughening the surface and shaping the hole to provide a mechanical key. Priming with cement mortar or a polymer bonding agent will develop additional chemical bond between the old and the new concrete.

Placing - For large cavities, replacement concrete may be used for economy. The use of admixture to improve fresh concrete properties and to avoid shrinkage are essential to develop good bond to the existing one. In difficult situations, the use of prepacked aggregate may be advisable with the mortar grouted in subsequently as for good quality, controlled gradation and satisfy flowability. The use of replacement mortar and concrete or equivalent materials such as polymer concrete, or high performance concrete, is common practice in localized repair of concrete structure. If reinforcement is corroded, the surface rust should be removed and where possible it is advisable to completely expose the outer layer of reinforcement to provide additional interlocking. Mechanical bond or chemical bond may also be provided to develop additional bond between the old and the new concretes. Alternatively, use of materials such as polymer concrete or latex modified concrete can be used to provide good bond by itself.

Overlaying - Overlaid techniques generally be applied to the surfaces where extensive deterioration does not warrant localized patching or placing. Normally the applied resurface is rather thin as for pavements, bridge decks, or slabs. The overlays are to be bonded directly to the underlying sound concrete and strong bond should be developed. The overlay should match the underlying concrete in thermal properties, or have good crack resistant properties. On vertical surface, pneumatic application may be used. In some cases, additional reinforcement is required, especially where considerable structural damage has occured, or when a thicker layer of new concrete is used. Conventional portland cement concrete using special quick setting admixtures is most commonly used, but the use of modified concretes, such as fiber-reinforced, regulated-set cement, or latex additions has been advocated (Fig.2).

Coating - Coating can be advantageous in preventing structural surface from direct contact to enviromental condition and in preventing water from entering structural elements. The thin layer of coating can be done by spraying, painting, or hand application. Various forms of manufacturing produce film, felt, paint and so on. Polymer materials such as epoxies, mastic, poly-eurethane ; poly-vinyl chloride, are commonly used. Some modification by adding filler or reinforcement is also available for more strength and more durable. The thermal properties, elongation and permeability have been advocated for some applications.

5. CASE STUDY OF STRUCTURAL REPAIR

Three examples of case study for structural repair have been introduced. Each cases represent different causes of deterioration and of structural damage. After structural evaluation have been made, then repair materials and techniques must be carefully chosen to suit the behavior, field expereinces and estimated durable performance. Figures 3 has shown an examples of material testing for repair work as shear-compression test. Another tests may involve shrinkage, compression, and flexural tests.

Case A : Concrete Chimney

A concrete chimney had been subjected to long-term deterioration from carbonation, especially on the top portion of the structure. The damage at top-most portion of the chimney where exposed to gas effluence, was so great that reinforcing bars were completely corroded; concrete was loosing and falling apart. Larger cracks had been observed at lower levels with large carbonation depth. The reinforcing bar had been corroded to the amount 20-25%. At lower zones, only small cracks have been observed with the maximum width of 0.04 mm and no corrosion on reinforcing bars have been measured.

The repair work involved almost every technique available. Epoxy injection was introduced for small cracks where there was no corrosion of rebars. Polymer modified mortar have been used for pressure grouting of larger cracks where the cavities have been washed out with high presure water jet and the corroded rebars have been inhibited by chemical injection. Topmost portions of the chimney where concrete was unsound and rebars were completely corroded, had been hacked down and then be replaced by a special type of nonshrink concrete with new reinforcement. Localized pathing mortar have been use in several places where small holes or spalling surfaces were inspected. Coating materials were also applied on the outside surface of the chimney in order to protect the concrete from direct contact with carbon dioxide.

Case B : Bridge Deck

An example of bridge deck where concrete was subjected to freeze-thaw deterioration. Concrete slab became loosen and several large cracks longitudinally and laterally had been observed. Slight corrosion on reinforcing bars has been measured and inspected. Unsound concrete can be examined to demonstrate deeper deterioration than mid depth of the concrete deck.

Repair method has been carried out by removing all unsound concretes. Rust has also been removed by sand-blasting. Formwork soffit has been erected by hanging from precast beams, and the polymer concrete has been placed to accommodate service traffic within 3 hrs of repair (Fig.4). This method can minimize traffic blockage and reduce traffic congestion during the repair.

Case C : Building

Small cracks and large deformation as a result of to large cavities in the beam as caused by of heavy reinforcement and improper consolidation. Ultrasonic pulse velocity was used to detect void size and location. Repair mathod has been introduced the epoxy injection to fill the void and to seal the cracks. (Fig.5)

6. CONCLUSION

In accordance with durability problems of structural concrete, the service life can be extended by routine inspection, proper repair and maintanance. Inspection work must be carried out to evaluate the repair work and for decision model of maintenance, repair, demolition or replacement. Tests methods and monitoring system have demonstated the information on decision to satisfy the structural level, safety level, reliability level and cost index. Repair materials and techniques would be essential to warant the durability performance based on properties, proper evaluation, mechanical response and field experience. Excellent repairs can be achieved, only when adequate information, sufficient tests, effective investigation, and reliable operation, have been carried out.

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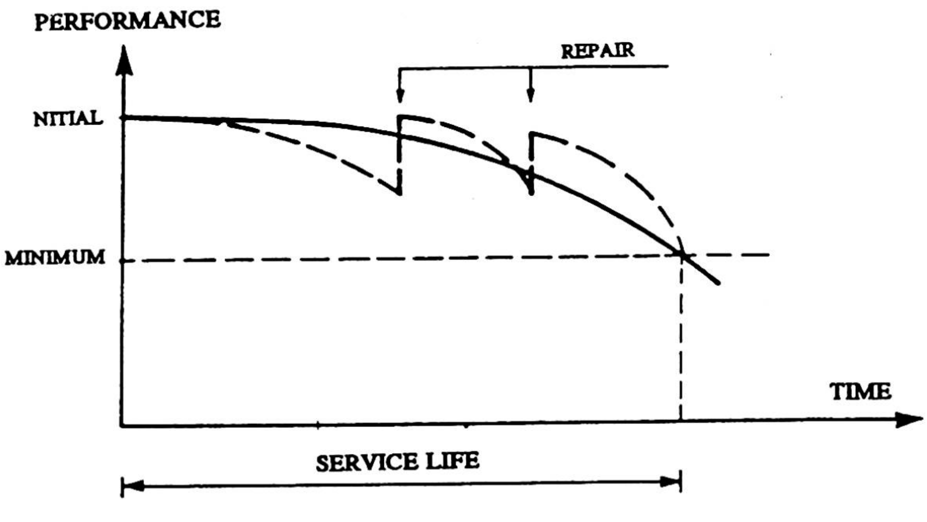

Fig. 1 Durability performance and service life of structures.

Table 1 Checklist for investigation of deteriorated concrete

Item	Description	Investigation check lists
1.	Concrete under inspection	- Concrete structures - Sample from a structures - Lab specimen stored on site - Lab specimen stored on lab - Sampling procedure - Sample storage and treatment
2.	Initial data on Concrete	- Concrete structures (design, load, dimensions) - Concrete specification - Mix design - Tests on materials - Quality control of fresh concrete - Quality in placing - Duration and method of curing - Age at time of attack
3.	Influence from the environment	- Temperature - Humidity - Pressure - Permeability of surrounding media - Sea-Water - Other aggressive substances - Type of contact - Concentration of aggressive substance - Frequency of exposure - Special environmented influences
4.	Visual sign of deterioration	- Erosion - Spalling - Exfoliation - Dusting - Crumbling - Softening - Staining - Pop-outs - Cracks - Liquid gel exudation - Crystallization - Corrosion of reinforcement - Mis-alignment
5.	Laboratory examination and tests	- Visual examination - Chemical analysis - Mechanical test - Physical test - Void location - Rebar location and condition - Water penetration test - Others

Table 2 Strength Testing

Test Method	Principle and Main Application	Test Standard
Core Testing	Determine in-situ strength of concrete. Compressive strength, tensile strength and modulus of elasticity can be obtained. It can be used with N.D.T. for calibration value of lowest strength.	ASTM C 42 ACI-318-89 BS 1881 Part 120
Rebound Hammer	Measures surface hardness by spring driven hammer striking concrete surface and rebound distance is given in R. values. It can be applied for estimation of compressive strength uniformity and quality of concrete.	ASTM C-805-79 BS 1881 Part 202
Pull-out Test	Measures the force required to pull out a steel rod with enlarged heal cast in concrete. It is for estimation of compressive and tensile strength of concrete.	ASTM C-900-82 BS 1881 Part 207
Break-off Test	Measures the force required at the top and at right angle to the axis to break-off the core at the bottom. The flextural strength can be estimated.	BS 1881 Part 207
Penetration Test (Windsor Probe)	Measures the depth of penetration into the concrete. Surface and sub-surface hardness are used to estimate compressive strength, uniformity and quality of concrete.	ASTM C-803-79 BS 1881 Part 207
Ultrasonic Pulse Velocity	Measures the transit time of an induces pulse compressional wave propagating thru the concrete. It is useful to estimate the quality and uniformity of concrete. It can also locate voids in concrete.	ASTM C-597-83 BS 1881 Part 203

Fig.2 Overlaying

Table 3 Test for Void Location

Test Method	Principle and Main Application	Test Standard
Endoscope	Lens and illuminating system which is inserted into a small diameter hole to inspect the interior cavities.. The main application for checking void along grouted prestressed tandons.	
Radiography	Gamma radiation atteñuated when passing thru the concrete. Extent of attenuation controlled by density and thickness of concrete. The location of cracks, voids and internal part (rebars) can be obtained.	BS 1881 Part 205
Radar	High frequency electromagnatic pulse are set into concrete and the reflected pulse are processed graphically Voids as well as reinforcement can be located.	ACI-581-62
Thermography	Measure infra-red radiation and is used to determine the surface temperature differential of concrete member during heating and cooling. It is advantaged in locating delamination and voids.	Ref: Manning D.G. &Holt F.B., 1980
Tomography	Gamma-ray source is collimated to form flat fan of ray that are attenuated as they pass thru the structure to detectors. It is used to locate void and reinforcement.	

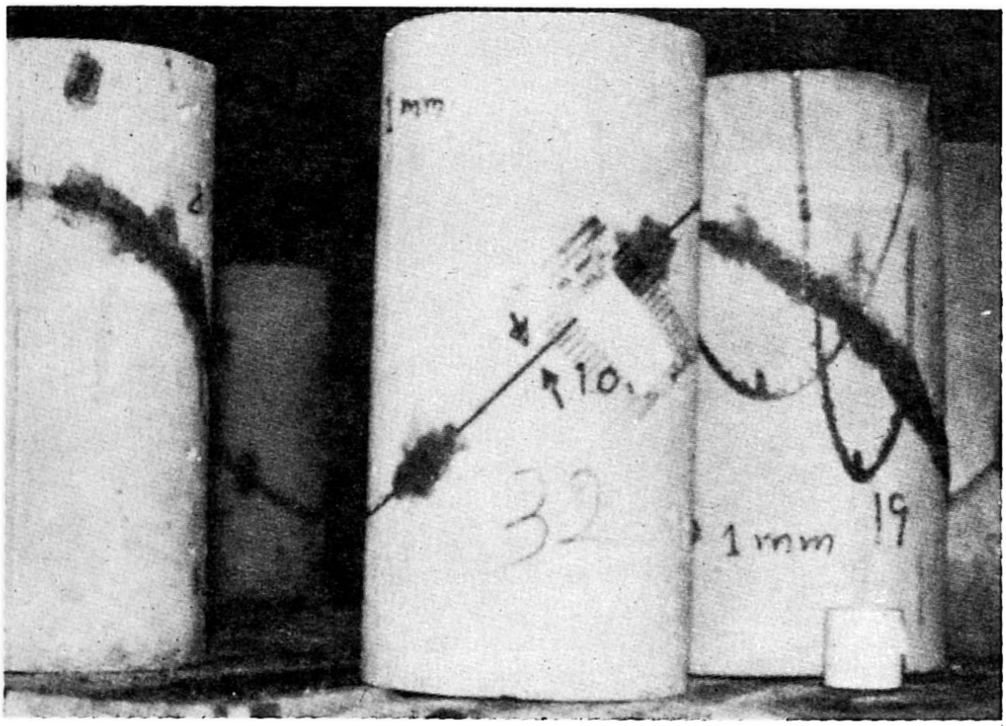

Fig.3 Shear-compression tests

Table 4 Water Penetration Tests

Test Method	Principle and Main Application	Test Standard
Absorption	An over dried specimen of known dimensions is cooled and immersed in water for 30 minutes. The quality and particular the obsorption of concrete in relation to durability can be obtained.	ASTM C 462-82 BS 1881 Part 122
Permeability	Measures the flow rate of water thru the concrete. It will indicate the degree of protection to reinforcement offered by the cover.	NBN 748.18 ISO/DIS 7032
Air Entrainment	By examining a concrete sample impregnate with a dye under the stereo microscope. Effective protection of cement paste from freezing and thawing cycles.	ASTM C 457-82
Initial Surface Absorption	Measures the flow rate of water into the surface concrete. The quality of concrete can be indicated.	BS 1881 Part 211

Table 5 Chemical Tests

Test Method	Principle and Main Application	Test Standard
Cement Content and Aggregate / Cement Ratio	Chemical analysis of the crushed concrete to determine cement content and aggregate to cement ratio.	BS 1881 Part 6 ASTM C 85-620
Water / Cement / Ratio	Measure the combined water present as cement hydrates and the capillary water. The water content can be determined from the sum of combined and capillary water to give the water to cement ratio.	BS 1881 Part 6
Cement Type	Chemical analysis of the crushed concrete sample based upon the dermination of Al_2O_3 and Fe_2O_3 atomic spectrophotometry. If the ratio of Al_2O_3 : Fe_2O_3 is less than 0.9 is SRPC and if the ratio is greater than 1.5 the cement is OPC.	BS 1881 Part 6
Carbonation Depth	Determined by spraying a solution of Phenolphtalene in alcohol and water onto a freshly cut face. An assessment of the time before the carbonation first reaches the level of the reinforcement can be made.	RILEM CPC-18
Choloride Content	Determination of chloride content of hardened concrete enables the corrosion risk to embeded reinforcement to be assessed.	BS 1881 Part 211

Table 6 Tests for Reinforcement Location and Condition

Test Method	Principle and Main Application	Test Standard
Electromagnatic Covermeter	Locates and measures the depth of reinforcement by utilizing an alternating current induced in a secondary coil caused by the proximity and active size of the reinforcement.	BS 1881 Part 204
Eddy Current Techniques	The equipment based on Eddy current techniques, is capable of indicating bar diameter and detecting bar at a greater depth. This is known as the Fe-depth meter.	
Reinforcement Potential	Electrical potential between the surface of the concrete and reinforcement measured. It is applied to determine the condition of reinforcement in the concrete.	ASTM C876-80
Resistivity	A row of four electrodes are held and a current passed between the outer and the potential drop measured between the inner., It provides a inner. It provides a measure of the maximum rate of corrosion affter the reinforcement becomes active.	Ref: Browne and Geoghegan (1978)

Fig.4 Bridge deck repaired by polymer concrete

Table 7 Repair Materials and Techniques

Repair Techniques	Material	Application
Injection	Epoxy resins Polymer modified	Fine Cracks
Pressure Grouting	Portland cement mortar Polymer mortar Putties and caulks Cement paste with filler	Large cracks Small holes/cavition Joints
Normal Grouting	Portland cement mortar Latex modified mortar Polymer mortar	Large Holes/cavition
Patching	Rapid setting mortar Polymer rasins Portland cement mortar (set control)	Localized area shallow
Placing	Portland cement concrete Polymer concrete Expansive cement concrete Latex concrete Epoxy concrete	Replacement
Overlaying	Asphaltic concrete Polymer concrete Expansive cement concrete Latex concrete Epoxy concrete	Thin layer surface
Coating	Polymer modifier Paints Mastic fult	Surface coating

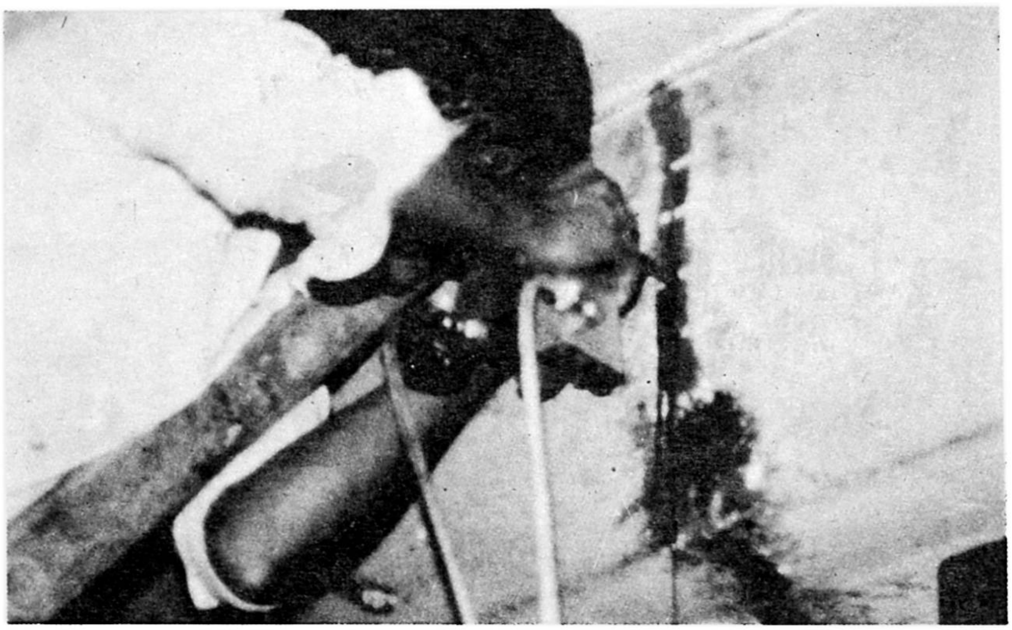

Fig.5 Building frame repaired by epoxy injection