TECVAC, Inc.

Technical Report

Student Activities Center Building
National Taiwan Ocean University

STRUCTURAL ASSESSMENT BY LOAD TEST PROVING

for

IN-SITU STRUCTURAL CRACK REPAIR PROJECT

USING VACUUM TECHNOLOGY

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ABSTRACT

This paper presents an analysis of the procedures and results concluded from load testing beams and columns repaired by vacuum injection at the Student Activities Center Building. The building is located on the campus of National Taiwan Ocean University. During and after the repair of the cracks by the patented vacuum injection method, a number of evaluation stages were performed to affirm structural restoration and safe occupancy of the building.

Prior to the employment of the repairs, an evaluation of the cracking included review of design and construction data. After evaluation, a description accurately locating and exactly depicting the existing cracks was recorded on drawings and accompanied with an overall evaluation of the existing concrete condition. The review conclusion and drawings were supplemented with photographs recording the condition of the individual members.

Considering the careful evaluation of the extent of cracking in the members, a method of repair was required that would restore strength, restore flexural stiffness and restore overall functional performance of the individual members. Because the vacuum injection/impregnation processes were fundamentally superior to conventional epoxy injection means, this method was selected for the repairs.

Upon conclusion of the repairs by vacuum injection, an investigation of the extent of depth and penetration of the repair resin materials in the cracks was performed. To validate the penetration of the repair materials into the depths of the fracture, core drilled samples were visually examined utilizing 7X scope. The scope was additionally utilized to visually examine the complete filling of the cavity and penetration of the repair materials in the fracture walls. Final load testing of the individual members and the structure was performed in accordance with applicable codes and accepted practices. The results of the testing concluded the repairs performed by vacuum injection completely

restored the structural integrity of the members and also revealed promise of mitigating reinforcement corrosion within concrete members with the repair process.

INTRODUCTION

Repairs to structural cracks were performed on a building situated on the campus of National Taiwan Ocean University. This three story structure, constructed in the mid 1960s' and known as the Student Activities Center Building, is located on the northeast coast of Taiwan, some thirty miles from Taipei. The building is constructed of concrete frame construction, composed of individual bays, each with two columns and haunched beams.

The building is located in the coastal area and suffers from many of the inherent problems. In particular, the area experiences many tremors each year. After a rather strong seismic disturbance, large cracks in the columns and beams were repaired by conventional pressure injection methods. Upon completion, the fractured members were examined and found to remain in a severely broken condition. This event prompted a complete structural safety investigation by the Chinese Institute of Civil and Hydraulic Engineering. This structural safety investigation concluded the building was, because of the cracked beams and columns, creating an eminently dangerous condition. The building was deemed off-limits and recommendations were to perform a more substantial and comprehensive evaluation and repair program. Evasun Engineering, Inc. was especially commissioned by the directors of the University to design and perform the repairs on a turn-key basis. A durable and effective method of restoring structural integrity and ensuring student safety was sought by Evasun.

After initial evaluation, it was concluded the only two options were to: (a.) remove the defective concrete and re-pour the member or, (b.) utilize a method of in-situ repair. The removal and replacement of the damaged and deteriorated concrete was concluded to be a prohibitively expensive preference, not to mention a lengthy intrusion on the student body and faculty. Therefore, attention was devoted by Evasun to employing a suitable in-situ repair.

Following a number of discussions with colleagues and structural repair specialist across Asia, the Middle East and the United States, Evasun learned of an acclaimed method of repair; a method of repair touted vastly successful under a wide range of applications and conditions. By creating a partial vacuum in the concrete, repair resins could be introduced into the fracture resulting in a more complete and permanent repair of the member.

The repairs were performed and completed under the participating direction of Evasun Engineering using the vacuum injection process.

EVALUATION, REPAIR AND TESTING OF DAMAGED CONCRETE MEMBERS

The objectives of the evaluation of the Student Activities Center Building were to: (a.) document the current condition of the individual members and estimate the influence of fracture conditions on structural integrity; (b.) determine the extent of the fractures; (c.) develop a method of repair. A cursory review of the as-built drawings was conducted. However, a tacit assumption was made by Evasun that the structure was designed and built adequately. Investigation of distress related to design or construction deficiency is beyond the scope of this paper.

Depiction of Existing Cracks

The safety investigation report of the cracked beams and columns of the Student Activities Center was comprehensively completed by the Chinese Institute of Civil and Hydraulic Engineering and reviewed by Evasun. A visual examination of the concrete beams and columns was conducted and all areas of cracks were observed for leaking, mineral deposits, rusting, spalling scaling and deterioration. The visual examination was somewhat hindered by the existing cementicious coating applied to the members. Selected areas of this material were removed and an electromagnetic device, known as a pacometer, was used to determine the depth of cover over the reinforcement (Ref 1.). Areas of thinner concrete cover were investigated by exploratory chipping and sounding.

Determination of the Severity

This closer visual examination by Evasun engineers revealed even more extensive and severe cracking than was reported by the findings of the CICHE report. Core samples were extracted from the more severely fractured members. It was discovered through the investigative core drilling that the interiors of the cracks were much more serious than observed from the outside surface area examination. Field examinations of the core samples by 7X scope revealed smaller fractures radiating from the main fracture line and even finer cracks radiating from the smaller connected cracks. In some instances, the interior of the fracture was in excess of 50mm in width, with total debonding of the cement paste from the reinforcing steel. For this reason, some of the outer material was removed to reveal and access the inner cracking for closer examination. It was also discovered that previous attempts to repair the fractures with conventional epoxy injection methods were totally unsuccessful. The exact location and classified severity of each crack was then recorded and verified as follows:

a. On the first floor level, 16 out of 25 (64%) columns contained severe cracking in the middle/center section of the columns and 4 out of 12 (33%) beams were severely cracked near the haunches.
b. On the second floor level, 7 out of 25 (28%) columns contained severe cracking in the middle/center section of the columns.
c. On the third floor level, 16 out of 25 (64%) columns contained severe cracking in the middle/center section of the columns.

The Repair Selection Process

The repair process to be employed by Evasun would necessitate the restoration of structural integrity to the members and, if economically feasible, the method would also provide extended serviceability to the individual members and the entire structure.

Selecting the repair system involved the consideration of the following criteria: (a.) economics; (b.) disruption of the repairs to the faculty and student body; (c.) ability of the method to be applied to the existing structural member conditions, and; (d.) consideration of the remaining structural service life.

The University requirements dictated the economics and disruption elements of the selection process. Their budget to perform the repairs were limited; the repairs must impose as little disruption to the facilities as possible, and; the repairs must be conducted at an expeditious pace to accommodate the late summer resumption of the university's scheduled opening. Either of the requirements imposed by the University eliminated the option of tearing out and re-pouring the individual damaged members so an in-situ form of repair was sought.

Pressure injection with epoxy material was first considered. However, the previous attempts at repairing the fractures by means of conventional pressure injection of epoxy were totally unsuccessful. The viscosity of the epoxy repair material prohibited penetration in all but the largest part of the fracture to a depth only just below the surface of the member. The fractures radiating from the main fractures were totally void of any repair material at all. Where the epoxy had penetrated to any degree, apparent moisture within the crack had totally prohibited any form of bond to the side wall areas. More than a few of the previous attempts resulted in the epoxy material remaining just below the surface, probably due to improper application procedures. Notwithstanding, fresh epoxies will not adhere to cured epoxies. It was determined where the previous repairs were partially filled with epoxy and unbonded to the fracture wall, this existing material would block the flow of new repair material and form a relief at the existing epoxy/new epoxy joining line. The entire repair would be rendered ineffective. Therefore, an alternative means of in-situ repair was preferred and explored.

After numerous conversations with colleagues, Evasun was informed of an in-situ method of repair that utilized vacuum technology in the repair of concrete, masonry and stone. American technicians had a number of successful repairs in the United States and Europe under a wide and extensive range of conditions.

The method is fundamentally based upon first creating a partial vacuum within the concrete and then introducing a repair resin into the concrete matrix. The process treats four basic conditions with four basic repairs: (a.) Vacuum installed plate bonding to strengthen and increase structural load capacity. (b.) Vacuum injection/impregnation of individual and discreet cracks; (c.) Impregnation flushing to impregnate surfaces and completely fill multiple and intimately spaced cracks in a wide area, and; (d.) Vacuum injection/impregnation of delaminated surfaces that eliminates the requirement of material removal. The vacuum injection/impregnation of individual and discreet cracks was used on this project.

The resin fills the cracks, including micro cracks down to a width of 5 microns (see Reference 6). Upon curing, the repair resin bonds the fractured and fissured matrix into a monolithic structural member of exceedingly high strength. Partial vacuum creation and repair resin introduction are achieved by adhering vacuum and introduction porting devices onto the fracture being repaired. By means of special tubing, the porting devices are connected to the vacuum source and the partial vacuum pressures are applied to the enclosed system. The repair resins are introduced, while maintaining the negative pressures, to fill the major cracks, interconnected cracks and voids and micro cracks. The concrete matrix of the walls within the fracture is impregnated with the repair resin materials.

Excessive moisture is evacuated from the concrete matrix of the fracture wall surfaces along with any deleterious gases and/or materials. The concrete drying process can be monitored by using in-line hydrometers installed in the special vacuum tubing.

In terms of meeting the objectives of Evasun in completing the repairs to the damaged members of the Student Activities Center, the vacuum process offered the following advantages over pressure injection methods:

- Repairs could be completed in a relatively short period of time with no sacrifice to the quality of the repair.
- Repairs could be completed within the price perimeters of the University budget and were competitive with conventional pressure methods of repair.
- Efficient and complete filling of existing fractures, interconnected fractures and voids and the complete filling of micro fractures.
- Total absence of pressure pockets would ensure and facilitate deeper fill of repair resin.
- Evacuation of moisture from the interior concrete matrix of the fracture.
- No possible extenuation of the fracture due to absence of applied pressures.
- Ability to introduce ultra-low viscosity materials into the fracture areas that would pass by and bond to the repair materials existing in the fractures.
- Improved bonding due to the lack of bubbling normally associated with low viscosity, low specific gravity repair resins.
- Susceptibility of continued reinforcing corrosion would be significantly diminished because of the evacuation of, and sealing out of, moisture from the treated concrete matrix.

Repairs to the Columns and Beams by Vacuum Injection/Impregnation

When the exact location and classification of severity were ascertained, technicians and special vacuum equipment were mobilized to the site of the work from contractor offices in Washington, DC. After condition evaluation and review with the specialty technicians, a uniquely blended acrylic polymer material, methyl methacrylate (MMA), was selected as the material to be used for the repairs (Ref 2. & 3.). This low viscosity, high strength material was particularly developed with special modifiers for the of vacuum injection processes. It is noted for its ultra low viscosity (5-15 cps) highly rated physical properties, flexibility, and its superior bonding and wetting properties. The material is not temperature sensitive and is easily mixed and modified for specific field conditions. Unlike epoxies, MMA is favorably forgiving when not mixed "just right" and will easily bond to previously cured MMA or epoxy.

The odor of the monomers, and toxicity commonly associated with all polymer components, required the usual precautions for handling. Foremost with the use of MMA was the proper and adequate ventilation of the emitted vapors (Ref 4.). The technicians employed high volume air moving exhaust equipment that totally exhausted the vapors from the work area to the outside.

Materials **-** The basic monomer of the repair material was methyl methacrylate (MMA). MMA is a slightly amber liquid that looks like colored water and is about the same viscosity. It has a sharp odor that can be detected by smell in as little as one part per million. An inhibitor is added for longer storage times.

Inhibitors are additives used in MMA to prevent premature polymerization, that can be caused from excessive temperatures, contaminates, etc.. The two most common inhibitors are methyl ester of hydroquinone (MEHQ) and hydroquinone (HQ). These inhibitors and promoters are normally added to the monomer by the acrylic manufacturer and require no field mixing or attendance to whatsoever. Promoters are used in very small quantities to increase the decomposition rate of the initiator, which will result in faster curing of the polymer. The generally preferred promoter used is dimethyl-para-toluidine (DPT), a liquid with the same viscosity of the MMA.

The initiator is added to this mixture of MMA, MEHQ and DPT that initiates the polymerization process, or curing of the repairing resin. Benzoyl Peroxide is a white powder or liquid that readily dissolves in the MMA. The amount of initiator added to the MMA is directly related to the time desired for curing the polymer. Increased amounts of initiator will result in more rapid polymerization of the monomers.

Physical properties of the cured materials generally range in the area of 10,000 psi compressive strength, 7,000 psi tensile strength, 4,000 psi flexural strength and 7000,000 psi modulus of elasticity. (Ref 5.)

Repairs**-** The structural repairs were performed by senior vacuum repair technicians and Evasun Engineering, Inc. in two required phases. Each crack face on each column and beam was carefully fitted with access port devices attached to special hoses to allow the evacuation process and the induction of repair resin materials. To prevent the repair polymers from draining from the fracture during the repair process and insure vacuum pressure maintenance, the fracture line was sealed with a cementicious material heavily bodied and concentrated with latex additive. The entire fracture system was then tested for negative pressure breaches. After sealing the access ports and the entire fracture line, the closed system was evacuated down to a pressure of 0.8 to 0.14 in Hg absolute or less and maintained during the introduction of the repair resins.

Investigation of depth and penetration of repair resin materials in the cracks

After the repairs were completed, five individual cracks, previously noted as moderate to severely cracked, were selected to extract core samples for examination. These cores were thoroughly examined by microscopic method. Microscopic examination revealed the MMA resin material had not only filled the subject crack completely, but had also completely filled the previously undetected and connecting adjacent cracks. The bonding of the MMA was good in each case with concrete failure occurring first when testing stress was applied.

In one of the extracted cores where reinforcing was passed through, it is worthy to note it was found the MMA completely filled the area around the corroded reinforcement bar. This would indicate the mitigation of the corrosion process is performed with the vacuum methods of repair and warrants separate further study intended by the authors in 1995.

Load Testing of Selected Repair Members

To further substantiate and confirm, (1) the effectiveness of the repaired members, (2)the ability of the repaired members to meet the requirements of the code specifications and (3)the safe occupation of the structure, load testing was performed on an area previously noted to be the most seriously damaged in the structural frame of the Student Activities Center Building. The selected area included both columns and beams that were considered most serious. The details of the loading test processes are described as follows:

a. Test Criteria

1. Code §337, Technical Specification of Architecture (ROC)

2. ACI Code 318-89, Chapter 20.

b. Period of Testing

1. Three days, September 23-25, 1994.

c. Loading Method

1. With consideration given to time, feasibility, and safety, water was used to load the testing area.

Load Testing Procedures

In accordance with the code specifications referenced above, the criteria for the load testing of the flexural members were delineated as follows:

1. Base readings (the reference for deflection measurements) shall be made immediately prior to the application of the test load.

2. That portion of the structure selected for loading shall be subjected to a total load, including dead loads already acting, equivalent to 0.85(1.4D+1.7L). Determination of L shall include live load reductions as permitted by the general building code of which this code forms a part.

3. Test load shall be applied in not less than four approximately equal increments without shock to the structure and in such a manner as to avoid arching of loading materials.

4. Test load shall be removed immediately after initial deflection reading, and final deflection reading shall be taken 24 hours after removal of the test load.

5. If the portion of the structure tested shows visible evidence of failure, the portion tested shall be considered to have failed the test, and no re-testing of the previously tested portion shall be permitted.

6. If the portion of the structure tested shows no visible evidence of failure, the following criteria shall be taken as indication of satisfactory behavior:

a. If measurement maximum deflection d of a beam, floor or roof is less than l_t^2/20000h.(cm).
b. If measurement maximum deflection d of a beam, floor or roof is exceeding l_t^2/2000h.(cm) deflection recovery within 24 hours after removal of the test load shall be at least 75 percent of the maximum deflection for non-pre-stressed concrete.

7. Non-pre-stressed concrete construction failing to show 75 percent recovery of deflection may be re-tested not earlier than 72 hours after removal of the first test load. The portion of the structure re-tested shall be considered satisfactory if:

a. The portion of the structure tested shows no evidence of failure in the re-test, and;

b. Deflection recovery caused by the second test load is at least 80 percent of the maximum deflection in the second test.

Calculation of Test Load and Deflection

a. Calculation of Test Load:

The dead load is not considered since the structure was constructed a number of years ago. The live load considered is 300kg/m2, and the factor for live load is 1.7. With no reduction in live load, the test load is calculated to be 51kg/m2. This is equivalent to 51cm depth of water loaded to the members.

b. Calculation of maximum allowable deflection:

l_t=1143cm

h=70cm

$d=l_t^2/20000h=0.93cm=9.3mm$

Measurement of Deflection

a. Set five dial gages with the accuracy of 0.01mm to measure the deflections in different positions.

b. Visually observe with microscope to detect any possible cracks occurring during testing.

Loading Test Procedure

The test load was applied in four approximately equal increments. The deflections were read from the dial gages immediately after each test load was in position, all the while observing the members with microscope for the development of cracks. The test load was removed and the final deflection readings were taken 24 hours after the removal. The recovery of deflection was also observed.

Results of Loading Test

From the results of the deflection readings, the maximum deflection with 51cm depth of water loaded is 2.6mm. This deflection is smaller than the maximum allowable deflection of 9.3mm calculated from the code specification. Therefore, the deflection is satisfactory. During the test, the deflection displayed linear elasticity and no visible cracking was detected from the examination. After the load was sustained for 24 hours, the deflection was increased by only 0.12mm and there was no phenomenon of residue. The recovery is calculated to be 99 percent for regenerance. (See attached diagram.)

SUMMARY AND CONCLUSIONS

From the results of the load testing it is concluded the strength and stiffness of the structure after the crack repairs utilizing the vacuum repair process displays superior behavior and totally satisfied the requirements of the code specifications. The vacuum technology proved to provide superior abilities when compared with pressure injection methods. The repairs were totally completed in half the estimated time of conventional repairs at a comparable cost. Examination of cores extracted from the repaired areas with 7X scope revealed material 355mm deep at widths less than .025mm. Radiated fractures connected to the main fracture were completely filled and field shear testing failed within the concrete and not at the adhesion line of the fracture.

The repairs performed on the columns and beams of the Student Activities Center demonstrated the ability of MMA polymer systems to fully restore structural integrity to damaged concrete via in-situ vacuum repairs. While MMA is a liquid with varying degrees of volatility, toxicity and flammability, the repair resin has proven to be very fluid and will soak into dry concrete, filling cement matrix cracks and voids much the same as water. The merits of the low viscosity MMA materials, in concert with the vacuum processes, are evidenced by complete and total penetration of repair resin into the interior fracture walls of the repaired beams and columns of the reconditioned structure.

The safe occupancy of the structure has been totally restored and is evidenced by the exceptional results of the loading test performed in accordance with criteria imposed by the code specification requirements.

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REFERENCES

1. Construction Technologies Laboratories, "Petrographic Report," Metropolitan Transit Authority, Baltimore, MD., 1993.

2. Auskern, A., "A Review of Properties of Polymer-Impregnated Concrete", *Proceedings*, Conference on New Materials in Concrete Construction, University of Illinois at Chicago Circle, Dec. 1971, pp. 1-1X - 47-1X.

3. Kaeding, Albert O., "Building Structural Restoration Using Monomer Impregnation," Polymers in Concrete: International Symposium, SP58, American Concrete Institute, Detroit, 1978, pp. 281-298.

4. E.I. DuPont De Nemours and Co., Methacrylate Monomers Storage and Handling," *Bulletin* No. E-18881.

5. Fowler, David W., Meyer, Alvin H., Paul, Donald R., "Polymer Concrete Repair", Center for Highway Research, University of Texas at Austin, 1979.

6. Germann Instruments, "In-Situ Test Systems," Chicago, IL, 17 pp., 1994.