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REPAIR AND STRENGTHENING OF ASSUMPTION CONVENT LAMNARAI

- General
  - The building was a reinforced concrete school building three stories high of U-shape, which was constructed in 1997 and then donated to the school by a real estate company for using in teaching of elementary and secondary levels. The construction was carried out in a hurry during the time that economic recession was about to begin. When looked from outside, structure of the building was in a good condition. But when the school had an idea of adding the fourth story on top of the existing building, which was now deck of the building, drawings of the building were checked in detail. It was found that more than seventy beams which were 7 meters long could not support the new load. Thus, these beams were designed for strengthening with carbon fiber composites to make them be able to carry the new load safely. After the surface of these members was removed in the process of surface preparation, cavities inside the beams along with many cracks were revealed. When strength of the concrete was tested by means of Ultrasonic Pulse Velocity Method and by coring out concrete samples for laboratory testing, it was discovered that many parts of the concrete had low compressive strength and could be considered as unsafe. Before strengthening of the structure with carbon fiber composites but after the defective parts of the structure were repaired, load test was carried out. Results obtained from load test indicated that structural behaviors under the applied loads could be taken as acceptable. Thus, the structure was strengthened in the next step with carbon fiber composites as it was designed for earlier, with some modification made by considering results from load test. After the structure was strengthened, load test was carried out again. Results from load test carried out after strengthening indicated that the structure was able to carry the new load.

- Structural characteristics

  - The structure was reinforced concrete structure of a three stories building. Total space of the building was over 6,000 square meters. Floor system was precast concrete planks placed on beams with reinforced concrete topping. For every story, the design live load was 300 kilograms per square meter, except for the deck whose design live load was only 150 kilograms per square meter.

- Problems that prompted repair

  - Because number of students had increased to more than 1,000, the school committee had decided to increase space of the building by building a roof over the deck of the building and adding walls in order to transform it into classrooms and laboratories with total available space about 2,000 square meters.
  - At the first time that the building was put in service, it was found that there was leaking of the deck and dripping of rain water. At that time, waterproof membrane was placed all over the deck and then topped with reinforced concrete about 8-10 centimeters thick. Their total weight was about 190-240 kilograms per square meter. This was higher than the design live load of the deck, which was only 150 kilograms per square meter.
  - To transform the deck into classrooms and laboratories, there must be structural improvement of the floor system to allow for live load not less than 300 kilograms per square meter, as specified in Thai Building Code.
  - When covering was removed, it was found that many beams were in poor conditions due to substandard construction. Cavities and cracks could be found in more than 50 beams and 30 of them were in serious condition. Cavities were also found in 20 joints where beams met with columns.

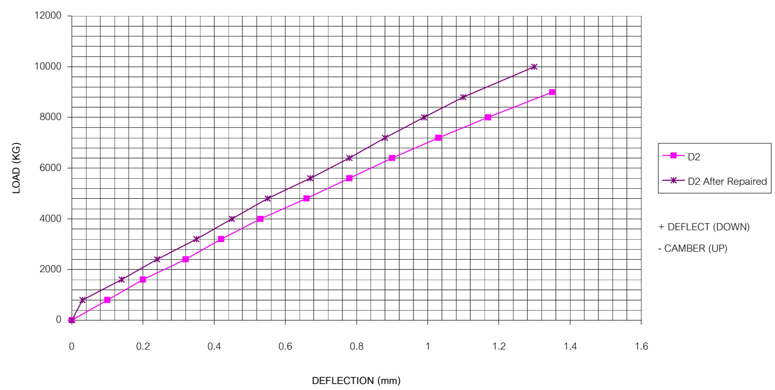



- Inspection/ evaluation methods

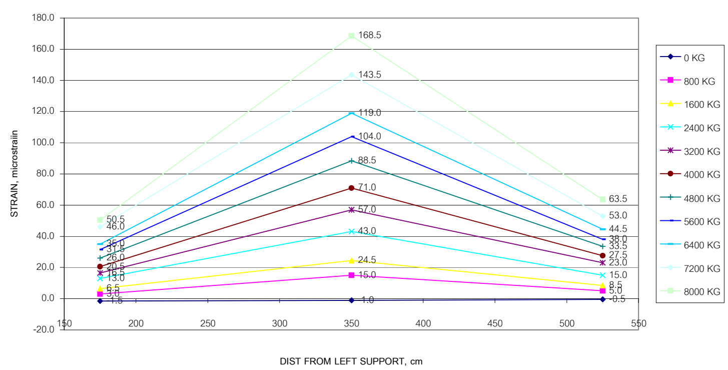
  - After defects of the structure were discovered, the Ultrasonic Pulse Velocity Method was used for checking of defects in the structure. By using this method, many areas that were in need for repair were located. In addition, coring was made and concrete samples were tested in order to determine compressive strength of the concrete. It was found that the beams that were in serious condition had compressive strength of concrete about 100 kilograms per square centimeters, which was considered as very low.
  - By considering results obtained from testing, it was necessary to test load carrying behavior of the structure so that structural evaluation in terms of safety of the structure could be made. Hence, all the beams with defects were repaired by means of grouting and epoxy injection, also by replacing the low strength concrete with high strength repair mortar. After that, the areas to be tested by load test were located, totally 10 areas.
  - Load test was done with beams of different boundary conditions, which were one span beam, two spans continuous beam, and three spans continuous beam. Observation was made on load carrying behavior and transferring of forces among members. In doing so, electrical resistance strain gages were installed on steel reinforcement at the designated locations. Dial gages were also installed to measure deflection of beams. After that, load was applied on top of the beams by using sand bags. Strains in reinforcing steel and deflection of the beams were recorded at different load levels until the load was increased to 150% of the design live load.
  - Load test was carried out three times. The first load test was done as evaluation for strength of the defective structure after concrete repair was done. As it would indicate whether the structure could be repaired and strengthened to make it safe enough to be put in service. The second test was to measure and record strains in steel reinforcement and deflection of members before strengthening. The third test was to evaluate efficiency of structural strengthening by means of carbon fiber composites. Evaluation was done by comparing results from the second test with results from the third test at the same load

level. By installing of electrical strain gages on carbon fiber sheets and carbon fiber rods, occurring strains under different test loads could be measured. Thus, maximum load carrying capacity of the already strengthened beams while still remaining within an elastic range could be estimated.

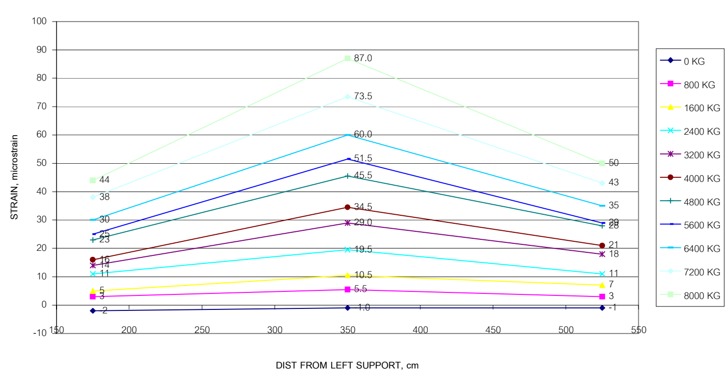
LOAD VS. DEFLECTION - BEAM B234 (LOAD STEP 1)



STRAIN DISTRIBUTION (PROFILE) IN CARBON FIBER RODS (BEAM B1) - AFTER REPAIRED



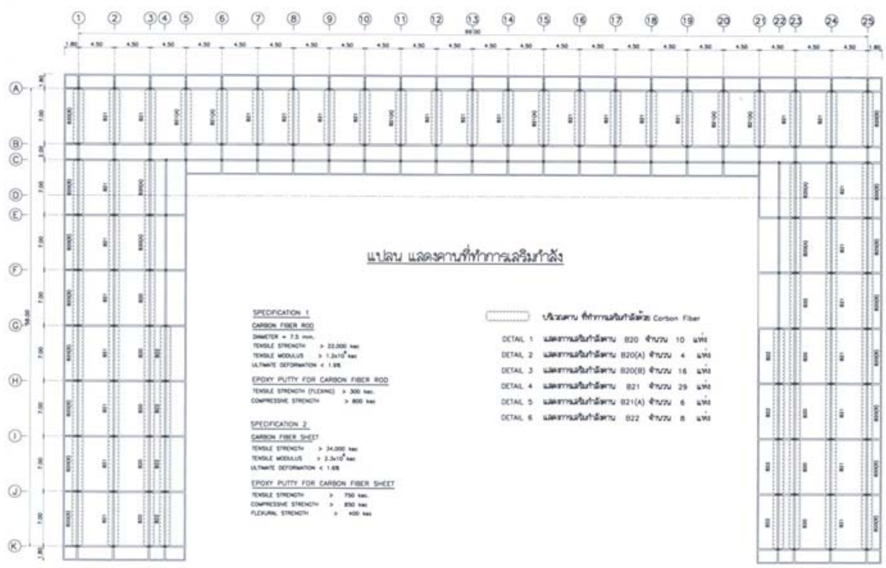
STRAIN DISTRIBUTION (PROFILE) IN CARBON FIBER SHEETS (BEAM B1) - AFTER REPAIRED



- Test results
  - Results from the first load test indicated that the beams with defects that had been repaired already were strong and good enough for being strengthened. Stiffness of these beams was much higher than the calculated value. It was also found that composite section was formed between beams and precast slabs.
  - Results from the second and third load test indicated that stiffness of the beams having defects and then strengthened by using carbon fiber composites was improved. Under 300 kilograms per square meter test load, strains in the reinforcing steel of the strengthened beams decreased about 20% and their deflection decreased about 15%.
  - Variation of strains in carbon fiber sheets and carbon fiber rods under the different test loads indicated bonding between them and the structure and that their function in taking tensile force could be performed efficiently with good stress distribution.

- Repair system selection
  - Carbon fiber composites were selected for beam strengthening to increase flexural strength and shear strength so that they would be enough for carrying the design load without significant changes of members' dimensions. 300 grams per square meter uni-directional carbon fiber sheets were mainly used for this. For the beams having high load carrying capacity, carbon fiber rods were additionally installed at the bottom so that no more than two layers of the carbon fiber sheet would be applied.
  - Cracks in beams would be injected with low viscosity epoxy by using the low pressure injection method.
  - Cracks that significantly effected structural performances of the structure would be repaired by means of stitching with steel rebars and carbon fiber sheets.
  - Cavities in beams would be repaired by taking out poor concrete and filling the cavities with high strength grout.
  - Cavities in the joint where column met with beams would be repaired by removing poor concrete and installing steel jacket around top of the column. After that, the cavities would be filled with non-shrink grout.



- Site preparation
    - While repair and strengthening of the structure was carried out, more than 1,000 students and teachers were using the building. The school was still opened and classes were held as normal. Thus, working area must be divided in to small zones and sequence of the work must be planned carefully to ensure that users of the building would be least disturbed and that safety of both users of the building and the workers would be guaranteed. As result, working area was divided into 4 zones and sequence of the work was drawn up by coordinating with the school director as an effort to match sequence of the work with activities of the school.

- Surface preparation
    - Initially, surfaces on both sides of the beams and at their bottom were rough and not smooth with low strength concrete in some parts. Thus, concrete in those parts was removed mechanically with electrical and pneumatic hand tools. The surface was then patched with repair mortar in order to obtain smooth, strong and clean surface for installation of carbon fiber sheets.

- Repair process execution
    - Strengthening of the beam with the carbon fiber rod

        - Alignment for rod embedment was marked on the underside of the beam, whose width was always 20 centimeters. Two parallel lines were drawn and concrete was cut into one centimeter wide and one centimeter deep groove running along entire length of the beam. The groove was then cleaned.
        - Layer of epoxy adhesive about 0.75 centimeter thick was placed at the bottom of the groove and the carbon fiber rod was embedded inside the epoxy. After that, the overflowing epoxy was trowelled to obtain the smooth surface.
    - Strengthening of the beam with the carbon fiber sheet
        - Before installation of the carbon fiber sheet, surface preparation was done.
        - Epoxy primer was applied to improve the bond strength of the system.
        - Epoxy putty was applied for leveling and smoothing the surface.
        - Fiber sheets were installed with an epoxy adhesive to strengthen the structure.
        - Pull-off test was done and it was found that the sheet bonded very well with concrete surface.

- Unforeseen conditions found
    - Originally, main objective for structural strengthening was to increase load carrying capacity of the beams due to modification of the structure. Later when covering was removed, many defects were found. To strengthen the structure more than 70%, the structure must be repaired first. Low strength and segregation of the concrete were also problems. Thus, many kinds of testing were required before the structure could be strengthened.
    - As result, timing and sequence of each process to be taken were greatly effected. Originally, it was planned that all the work could be finished within 45 days and would be done during school holiday, which would make it easier. But due to the fact that the structure had a lot of defects that must be repaired first and load test must also be done, working period was extended to 90 days and the work must be done when the school was still opened and more than 1,000 people were using the building.

- Special features that make the project worthy of an award
    - Repair and strengthening of the structure having a great number of defects and damages from poor quality construction while the building was still serving more than 1,000 people, mostly children at elementary levels, must be done with the highest level of carefulness. Great attention must be paid on safety of the children. Also, the work must be done in the way that would have least impact on teaching of the school.
    - Load test was done with the building for many times and with many parts of the structure in a limited time and results from load test were used in evaluating safety and efficiency of structural strengthening with carbon fiber composites.