Civil Engineering Dimension, Vol. 14, No. 3, December 2012 (Special Edition), 205-208 CED 2012, 14(3), DOI: 10.9744/CED.14.3.205-208
ISSN 1410-9530 print / ISSN 1979-570X online

Technical Note:

Structural Strengthening using Carbon Fiber Reinforced Polymer

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Note from the Editor: This paper presents practical pointers to be considered in strengthening concrete structure with Carbon Fiber Reinforeced Polymer (CFRP) which becomes more popular nowadays. It is pointed out that the strengthening process consists of assessment, design, and installation andthat should be done by people who are competent, experienced, and professional in their field.

Keywords: Strengthening Method, Strengthening Material, Carbon Fiber Reinforced Polymer.

Introduction

Nowadays, construction engineers are more frequently faced with tasks of strengthening existing structures, due to many different situations as:

- Facilitate the structure/architecture changes and a higher load-carrying capacity.
- Accommodate the loads that were not anticipated in the original design.
- Error in construction (e.g. misplaced or missing reinforcement and inadequate concrete strength).

Many strengthening are done on existing structure that still in operation, and cannot be interrupted or closed within a long time, thus the strengthening must be finished as soon as possible. Therefore the design and installation of the strengthening are often done in an inappropriate way.

To get a strengthening that is effective, cost-efficient, and achieves the target that already been set up, some consideration is needed in doing the strengthening through assessment, design, and installation. All of these stages are very important and none of them can be ignored. The assessment, design, and installation have to be done by people who are competent and professional in their fields.

Strengthening Consideration

The purpose of strengthening is increasing the capacity of the structural member to resist new load due to structure/architecture changes or design load. Strengthening of existing structures will always deal with such circumstances, whether space restrictions, constructability restrictions, durability demands or any other issues. All of the information above is required to design the strengthening solution.

Strengthening design process:

- Structural assessment
  Reviewing the existing drawings, reports, and calculations, verified by an on-site inspection, and some non destructive or semi-destructive test, if needed, as well as determining the loading history and material characteristics of the structure.
- Structural analysis
  Determining the type and level of structural deficiency that need to be strengthened, by comparing the existing load capacity with the required capacity based on new load.
- Strengthening method and material
  Selecting the best strengthening method and material by considering the constructability issues, building operations during installation, environmental exposure after installation, final appearance, and cost-efficient.
- Installation
  Follow the method statement that consists of detail installation procedure and quality control that needed for analysis the strengthening result.

Strengthening Methods and Materials

Strengthening methods and materials that are commonly used in Indonesia:

- Span Shortening
  The span shortening method consists of erecting new support to shorten the span of an overstressed member. The new supports may consist of a vertical column or lateral beam, and can be constructed using reinforced concrete, structural steel shapes or a combination thereof. This method is very effective for increasing load-carrying capacity of existing horizontal members that are dominated by flexural behavior. The designer should verify the changing of the stress condition due to the additional supporting member.
- Section Enlargement
  Section Enlargement is the placement of an additional concrete on an existing structural member, commonly using Self-Compacting Concrete or non-shrink cement grout with or without additional coarse aggregate. As a result of the addition

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of these dimensions, it should be observed that the overall weight of the building is increased, so a thorough analysis of the upper structure until the foundations must be done.

- External Post-tensioning
  Post-tensioning can be used to counteract tensile stresses and deflections from applied loads. Special care should be taken within the anchorage zone, to ensure an effective transfer of post-tensioning force between the existing structure and the post-tensioning system.
- Steel Plate Bonding
  The purpose of this method is to increase the capacity in flexural, shear, and confinement, by providing additional tension reinforcement that shares load with the existing reinforcement. Commonly, to achieve composite behavior between steel plate and existing concrete, an epoxy resin is used either in a paste consistency or as a liquid injected under pressure.
- Fiber Reinforced Polymer (FRP).
  The principle of FRP bonding is the same with steel plate bonding. FRP material that are available in the market is Carbon FRP (CFRP), Aramid FRP (AFRP) and Glass FRP (GFRP). CFRP are typically used for sustained loads due to higher strength, stiffness, durability, and creep resistance. CFRP is available in plate (strip) and fabric (wrap). Figure 1 shows various applications of CRFP.

Strengthening using CFRP

CFRP is used for strengthening in Indonesia since 1997. Nowadays this method become popular, due to some clear advantages reasons as follows:

- Material
  As shown in Figure 2, CRFP is a hHigh tensile material with Modulus of Elasticy is similar with steel. Another advantage of CRFP is the light weight and corrosion free properties.

Figure 1. Strengthening for Concrete Structure using FRP System

- Application
  Due to its light weight, CRFP is fast and easy to install. It can be installed without interrupting the operation (possibility to open traffic during the installation). CRFP could be used in areas with limited access (Figure 3) and can be supplied with no joint, even if the span of the structure is very long. Figure 4 and 5 show application of CRFP plate and wrap respectively
- Maintenance
  Since CRFP is corrosion free, no maintenance is required even in aggressive environment. This is very advantageous compared with steel plate.

CFRP Adhesive

Many strengthening are installed on an existing structure that is still in operation, for instance in bridge and car park. In such a case the closing of the traffic will be a crucial problem for the owner on the strengthened installation. To assure that CFRP system can be effective, the epoxy adhesive that is used for CFRP bonding must be cured perfectly even with dynamic and vibrating loads still working during the installation.

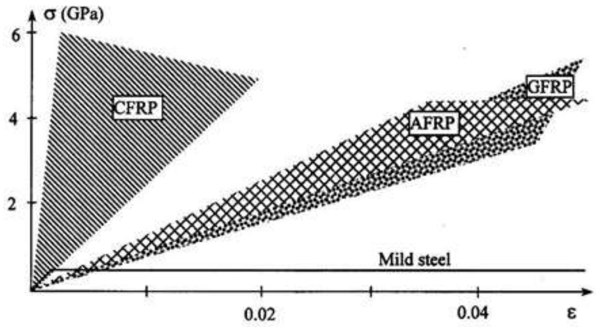

Figure 2. Stress-Strain Diagram

Figure 3. CFRP Application

Figure 4. Application CFRP Plate

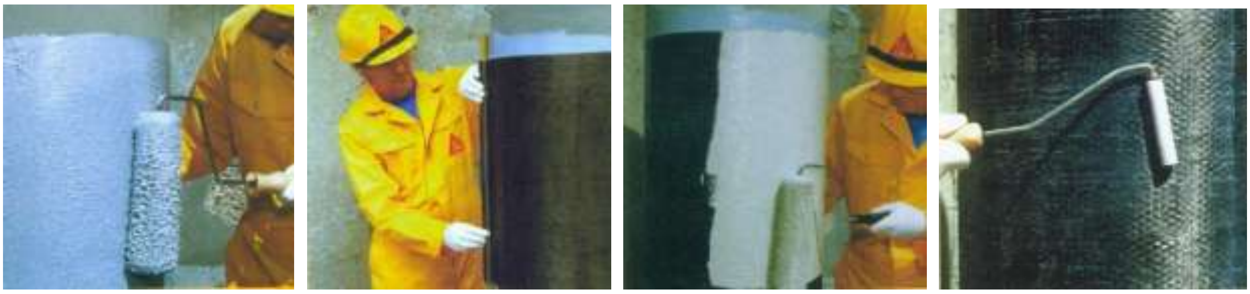

Figure 5. Application CFRP Wrap with 'Dry System'

To answer these problems, Sika introduced a special adhesive called Sikadur. Sika commissioned the Swiss Federal Laboratories for Material Testing and Research (EMPA), Dübendorf, to investigate the influence of dynamic and vibrating loads during curing of the structural adhesive (Sikadur), on the capacity of the structure.

Tests were performed in two phases on pre-stressed concrete slabs with span of 3.80 m and thickness of 18 cm (Figure 6). In the first phase, the CRFP (CarboDur) plates were installed under dynamic loading, and in the second phase, these strengthened specimens were subjected to static loading till failure. Figure 7 showed the CRFP debonded under ultimate load, and Table 1 showed the summary of the test result of the load-bearing capacity, F, mid-span deflection, δ, and strains in CFRP at debonding of test specimens, ε, of the specimens.

Figure 6. EMPA Test set-up

Figure 7. Failure-CFRP debonding

Table 1. Test Result

Test Specimen	F (kN)	δ (mm)	ε (‰)
Specimen 1 Curing without oscillation	161	70	6.61
Specimen 4 Curing with oscillation	176	75	6.55

F : Ultimate/Failure load
ε : strain in CFRP at delamination/debonding
δ : Mid-span deflection

Specimen 1 was cured with no oscillation while Specimen 4 was cured with oscillation.

It can be seen that practically there is no difference in the load-bearing capacity, mid-span deflection, and strains in CFRP at debonding of the two test specimens. Therefore, structures can be open to traffic during application of CFRP plate system.

Closing Remarks

To get a strengthening results that are appropriate and to prevent unexpected results, it requires coordination between the parties doing the assessment, design, and installation. The most important thing is that each stage must be done by parties who are competent, experienced, and professional in their fields.

The selection of the most suitable method for strengthening system depends on many factors including effectiveness, constructability, aesthetics, and cost. Sometimes, although the components of the strengthening option may be more expensive, they could be installed faster and with fewer interruptions to building operations, which could result in lower overall cost.

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