**Engineering International Conference "UNNES Conservation" 2013 Proceeding**
p- ISBN-979-25-2783
January 08, 2013, Semarang, Indonesia

# Strengthening Technology into Reinforced Concrete Structures

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***Abstract —*** *Strengthening technology into reinforced concrete (RC) structures has become a popular method to address the needs for maintaining and upgrading the strength of essential structures. The growth of research in the strengthening technology, followed by its many practical applications is recognition into the importance of the strengthening methods. Included in these methods are injections, jacketing (confinement), and structural member addition techniques. These are some of strengthening techniques in order to responds problem of retrofitting RC structures, as it increases structure's stiffness, strength and bending capacities. However, the effectiveness of strengthening method depends on its various types and techniques used, strength and ductility enhancements resulted; besides time and economic considerations. This paper describes some of strengthening techniques currently applied into RC structures, includes its application's liability.*

***Keywords —*** *Concrete, Reinforced Concrete, Strengthening Technology*

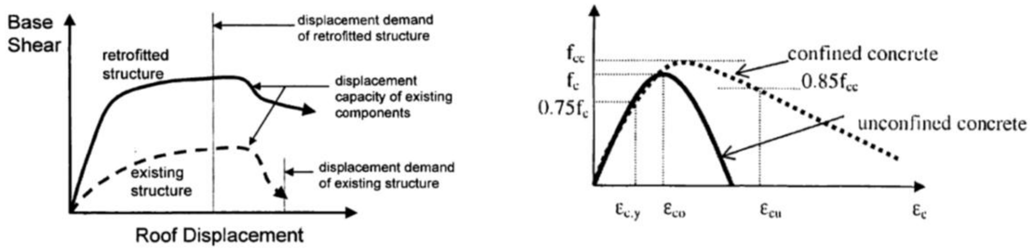
## I. INTRODUCTION

RC (reinforced concrete) is the most widely used construction material worldwide, due to its supremacy in strength, durability, resistance, shape versatility, low maintenance, and price. Some disadvantages of RC are its limits in carrying tensile forces, ductility and deflection capacities; beside it possess a significant self weight. The definition of concrete itself, is various among countries. AS3600 categorizes a concrete with a cylinder compressive strength < 65 MPa as NSC (Normal Strength Concrete), according to ACI the limit of NSC is < 41 MPa, according to Eurocode 2 and DIN 1045-1 it is ≤ 50 MPa. While outside those limit is categorized as HSC (High Strength Concrete) [1]. Many RC structures and infrastructures are currently ageing and/ or in damage, thus they are in the needs of maintenance, repair, and upgrading. Moreover, the major structures and infrastructures are substandard and deficient under current knowledge and modern codes. Even this applies in earthquake regions, even though the structures and infrastructures have already designed by relatively new seismic design. By considering these matters, structural strengthening and retrofitting are becoming more and more important.

Strengthening is a technique to address problems of upgrading and retrofitting RC members/ structures, as it increases stiffness, axial force and bending capacity [2]. The effectiveness of a strengthening technique depends on the choice of using a precise type and technique, strength and ductility enhancements resulted; besides time and economic considerations. This paper describes current various strengthening technologies applied into RC structures.

## II. STRENGTHENING TECHNOLOGY

Recent RC structures and infrastructures constructed by conventional design are usually initially damaged by brittle failure towards flexural yielding with a relatively small deformation. A strategy to strengthening such structures is by reducing the deformation and/ or force applied on the weak components by adding lateral stiffness, or otherwise reducing the loading applied. Such strategy is illustrated in Fig. 1.a, while the definition of limiting concrete's strain is shown in Fig. 1.b. [3].




(a) (b)

Fig 1. (a) Strategy in protecting brittle structural component by increasing stiffness and reducing load applied. (b) Definition of limiting concrete's strain.

In order to respond the damage of RC members/ structures and following the strategy to protect weak structural components, below is some strengthening techniques:

II.1 Resin or cement injection

It is the most widely used strengthening method from minor to medium size of cracks occurred in RC members/ structures. Resin injection is applied when the width of crack exceeds 0.2 - 0.3 mm. In the case of larger cracks with a width up to 20 mm, cement grout is more appropriate to use as the material injection [3]. Fig. 2 shows the practical implementation of resin injection on RC members/ structures.

Fig 2. Resin injection on RC members/ structures [4].

II.2 RC jacketing

Jacketing (confinement) is a technique to address problems of upgrading and retrofitting RC columns, as it increases columns' stiffness, axial force and bending capacity. Concrete, with or without reinforcement, is the most frequently material used for jacketing because its application can be handled easily. In concrete confinement, to achieve column composite's monolithic behavior, common practices are used such as: increasing roughness of the interface surface, applying a bonding material and steel connectors. Regarding the concrete mixture to be used and desired thinness of confinement, options of materials are usually a grouting of SCC (Self Compacting Concrete) and HSC (High Strength Concrete) [1].

The additional longitudinal and transverse reinforcements in RC jacketing can increase the member flexural and shear strengths, enhance the deformation capacity and improve the strength of deficient lap splices. RC jacketing into RC members/ structures is usually be done with an overlay of cast in situ concrete or shotcrete. For allowing the adequate placement of ties, the thickness of concrete overlay should be at least 75 mm; formwork is also needed for construction of the jacket [3]. Fig. 3 shows the design of RC jacketing and its practical implementation on a RC column.

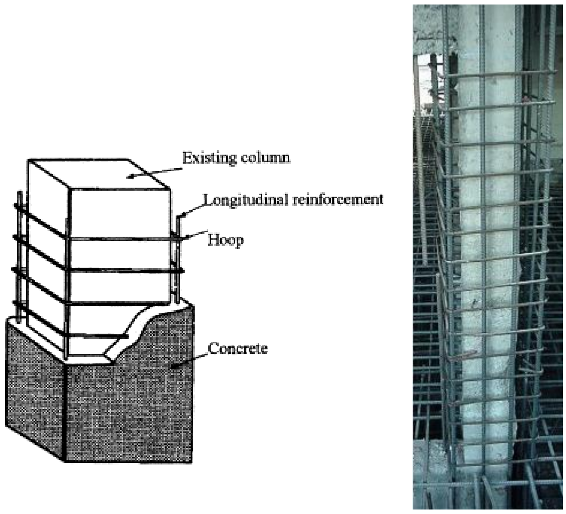



Fig 3. RC jacketing [5-6].

II.3 Steel jacketing

As well as RC jacketing, steel jacketing is another form of flexural strengthening technique on RC members/ structures, except the fact that the material is more expensive. However, it is fast and effective if there is an immediate need of its application on building, such as: after a damage earthquake, or where there is a danger collapse of a member/ structure [3]. Fig. 4 shows designs of steel jacketing, and an example of steel jacketing implementation on a RC column.

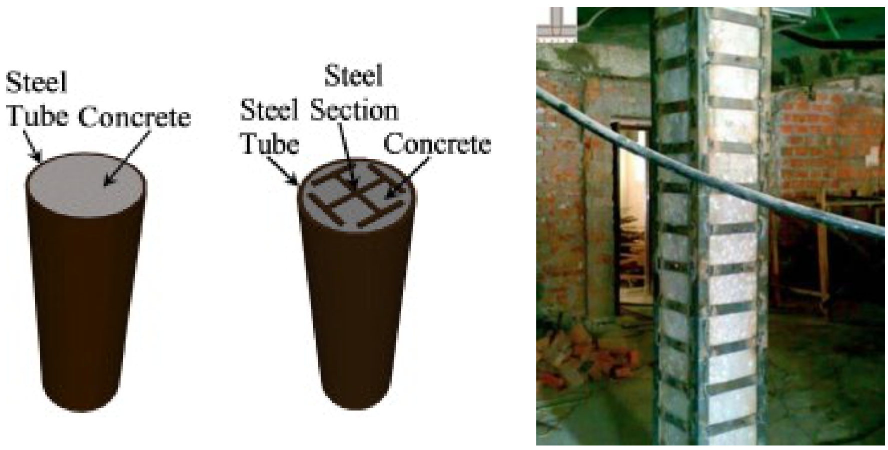



Figure 4. Steel jacketing [5, 7].

II.4 FRP jacketing

FRP (Fiber Reinforced Polymers) in the form of continuous CFRP (Carbon Fiber Reinforced Polymers), GFRP (Glass Fiber Reinforced Polymers), or AFRP (Aramid Fiber Reinforced Polymers) bonded in a matrix made of epoxy, vinylester or polyester are another type of strengthening technique. The benefit of its strength-to-weight ratio, corrosion resistant, easy handled and installation make FRP jacketing as a strengthening technique choice, despite its high material cost [3, 8]. Fig. 5 shows the mechanical properties of GFRP, CRP, and AFRP composites; and the qualitative of E-glass, Carbon, and Aramid fibers. Fig. 6 illustrates the stress-strain and volumetric response of FRP or steel confinement on concrete. While Fig. 7 shows the strengthening schemes of FRP confinement.

(a)

| Unidirectional advanced composite materials | Fibre content (% by weight) | Density (kg/m³) | Longitudinal tensile modulus (GPa) | Tensile strength (MPa) |
|---|---|---|---|---|
| Glass fibre/polyester GFRP laminate | 50–80 | 1600–2000 | 20–55 | 400–1800 |
| Carbon/epoxy CFRP laminate | 65–75 | 1600–1900 | 120–250 | 1200–2250 |
| Aramid/epoxy AFRP laminate | 60–70 | 1050–1250 | 40–125 | 1000–1800 |

(b)

| Criterion | Fibre composite sheets made of: | | |
|---|---|---|---|
| | E-glass fibres | Carbon fibres | Aramid fibres |
| Tensile strength | Very good | Very good | Very good |
| Compressive strength | Good | Very good | Inadequate |
| Young's modulus | Adequate | Very good | Good |
| Long-term behaviour | Adequate | Very good | Good |
| Fatigue behaviour | Adequate | Excellent | Good |
| Bulk density | Adequate | Good | Excellent |
| Alkaline resistance | Inadequate | Very good | Good |
| Price | Very good | Adequate | Adequate |

Fig 5. (a) Mechanical properties of GFRP, CRP, and AFRP composites.
(b) Qualitative of E-glass, Carbon, and Aramid fibers [8].

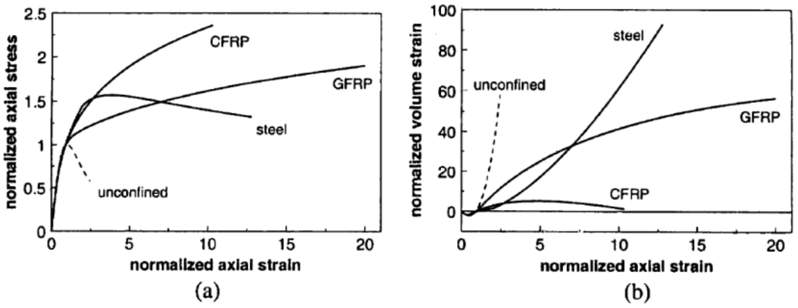



Fig 6. (a) Stress-strain and (b) volumetric response of FRP or steel confined concrete [3].

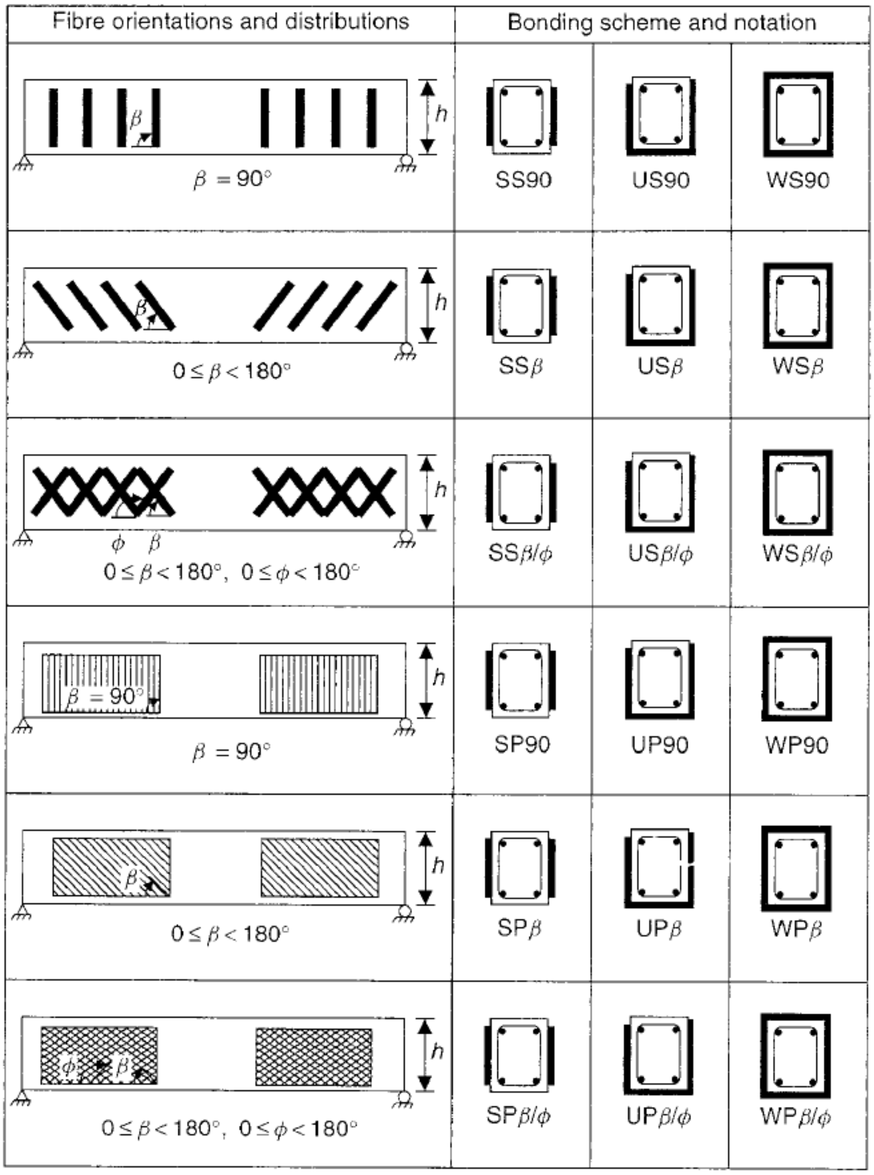



Fig 7. FRP strengthening schemes [8].

II.5RC walls addition

Another common of strengthening technique on existing RC members/ structures is the additional application of shear walls. This technique is very significant in order to manage global lateral drifts and reducing damage on frame members. It should be taken into account that as a result of the large cross sectional dimension of the shear wall, its deformation capacity is thus smaller than that in slender frame members. If the shear wall is added right above the foundation, there is no need to strengthen other structural components [3]. Fig. 8 shows the implementation of RC walls addition.

II.6 Steel bracing

The most convenient of strengthening concrete frames is by applying steel bracing technique, as this system gives a lateral load resistance on RC members/ structures through the horizontal projection of the axial force developing by the inclined braces. Diagonal bracing, X and V diagonal bracings are example type of the steel bracing system [3]. Fig. 9 shows the applications of steel bracing on RC frames.

Fig 8. RC walls [5].

Figure 9. Steel bracing [9-10].

II.7 External buttresses

In order to eliminate the disruption to the function of original buildings/ structures, external buttress can be constructed to increase the lateral resistance of the whole structure. The foundation schemes on buttress could possibly be eccentric footings (to avoid excavation of the original building/ structure foundation). Adding buttresses is an effective solution as long it is build using design principles and displacement based approached [3]. Fig. 10 shows example applications of external buttresses on RC structures. Next, in Table 1 a summary of strengthening techniques and its relative consequences is shown.

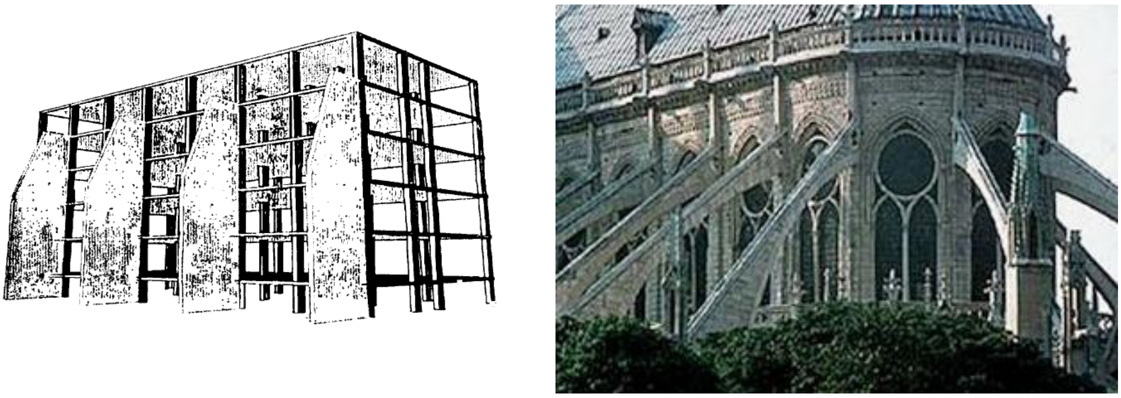


Fig 10. External buttress strengthening [3, 11].

Table 1. Summary of strengthening techniques and its relative consequences [3].

| Technique | Local Effect | Global Effect | Relative Cost | Disruption | Technology | Comments |
|---|---|---|---|---|---|---|
| Resin injection | Reinstates stiffness and strength | No global effect | Low-to-Medium | Low | Medium | Reinstatement approach |
| RC jackets | Upgrade stiffness and strength and (possibly) ductility. | Changes response characteristics. If applied to columns, it forces hinging to beams | Low, per member | Medium-to-high | Low, unless extensive welding used | Can remedy soft storey response. If in few storeys, can lead to soft storey above |
| Steel jacket or rings | Ductility and shear strength only; if strong composite action, stiffness increases | Increased global deformation capacity | Medium | Low | Medium | Effective where the main problem is sparse transverse reinforcement; fast implementation |
| Narrow FRP wrapping | Large increase in ductility; little effect on strength or stiffness | As for steel rings | High | Low | Medium-to-high | Suitable solution if cost is not a controlling factor |
| Beam-column joint wrapping by FRP | Eliminates shear failure in connections. | Reduces marginally global drift by reducing connection deformation | High | Low | Medium-to-high | As above |
| Complete FRP jacketing | Very large increase in ductility and shear strength; little increase in stiffness | Preservation of the stiffness distribution with drastic effect on strength distribution | High | Low | Medium-to-high | As above |
| Selective techniques | Measured and quantifiable increase in any one parameter or a combination of parameters | Tuned structural response to fit with performance objectives | Low | Medium | Medium-to-high (more in analysis and know how than in materials) | Most suitable and objective approach if analysis capabilities and specialized engineering expertise exists |
| RC walls addition | Could lead to increased force demands in the immediate vicinity | Drastic reduction in deformation demands on all other members. Resolves problems of soft storey. | Medium | High | Low | Most effective solution if disruption is not a problem. Drastic intervention to foundation needed. |
| Steel bracing | Protects brittle RC members in its vicinity from collapse. May introduce large forces at connections | Increases global ductility and dissipation capacity. May resolve problems of soft storey. | Medium-to-high | Low-to-medium (depending on external or internal application) | Medium | Sensitive to detailing of braces and connections against local buckling and post-buckling fracture. |
| Infilling of panels | Generates high corner stresses. Increases storey stiffness, hence reduces storey drift | Increases weight hence seismic loads. Reduces period, hence increases higher accelerations. May lead to modified global response if panels are monolithic, leading to cantilever response | Medium | Medium-to-high (depending on external or internal application) | Low | If applied externally and secured fully, it is an effective solution. Possibly by replacing masonry panels by precast concrete units |
| External buttresses | Generates very high local demand at connection with structure. | As in RC wall addition. | Medium-to-high | Low | Medium | Requires elaborate foundations. Uplifting is a problem. |

## III.LIABILITY OF STRENGTHENING TECHNOLOGY

Strengthening is a rehabilitation work, depends on the nature of its work, may cause disturbance such as noise, vibration, dust and other type of pollutions. Obviously, the strengthening technique used should be discussed with the building owners/ users, as it influences the cost, time and building function associated with disruption made by the rehabilitation work. Some factors that affect the choice of strengthening technique applied in degraded members/ structures are:

- strengthening versus work cost,
- level of strengthening and future impact of the new damage,
- strengthening materials and the availability of technology,
- consequences of partial or total operation work,
- restrictions on surrounding space and outlook of the structures,
- social, political, and/ or historical significances,
- requirements of repeatability and reversibility of the intervention,
- restriction or change of function/ use,
- partial demolition and/ or mass reduction,
- local or global modification on members and structures,
- transformation of non-structural into structural components,
- modification on the structural system,
- member replacement,
- addition of a new lateral load resistance system.

Based on above factors, each strengthening technique minimum consists of a special case, thus the choice of this technique should based on the one that provide best solution. Therefore, generalization of application in strengthening technique is not advisable [3].

## IV.CONCLUSION

This paper has described some strengthening technologies applied into RC members/ structures, such as: resin injection, RC and steel jacketing, FRP confinement, RC walls addition, steel bracing and external buttresses strengthening techniques. A summary table contains of the strengthening techniques and its relative consequences, and the liabilities of the strengthening technique application are also shown. However, this paper has not explained the theory and practical application of each strengthening technique broadly.

## V. ACKNOWLEDGEMENT

This paper is written as the writers' contribution to the Faculty of Engineering at the Semarang State University, Indonesia. This paper is a part of the first writer's knowledge gained during her doctoral study at the University of Kassel, Germany. During the first writer's doctoral study, all financial assistances especially provided by the Indonesian Directorate General of Higher Education, Indonesia; and the Chair of Concrete Structures of the Department of Civil and Environmental Engineering at the University of Kassel, Germany; are gratefully acknowledged.

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