An extensive analysis based on the most recent research is presented for existing reinforced concrete buildings' shock absorption and mitigation.

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Abstract:

Significant economic losses, severe injuries, and the loss of human lives have been caused by the collapse or substantial destruction of existing structures during powerful earthquakes. Considering the late adoption of new seismic standards and the enormous number of under-designed structures, the scientific interest in creating methodologies for the seismic upgrading of existing buildings has increasingly increased. In light of the fact that reinforced concrete (RC) buildings account for a significant amount of the existing stock, this study seeks to provide an overview of seismic upgrading procedures for RC structures. There are two types of retrofitting methods: local measures that improve the performance of certain components and global measures that affect the whole building. The focus will be on cutting-edge methods rather than more established ones.

Introduction

In most industrialised countries, the building stock has already begun to deteriorate significantly. 80% of European Union buildings were constructed before the 1990s, 40% before the 1960s, and a third of the structures were over 50 years old [1]. [2] [3] Buildings account up 36% of EU CO2 emissions and 40% of EU energy consumption, making the environmental effect of the ageing building stock enormous. A "Renovation wave" of EU and Member States' buildings [3] is emphasised by the European Green Deal [2]. A New European Bauhaus effort is being encouraged. It has also been found that historic structures have a poor ability to withstand earthquakes (e.g., in Southern Europe), causing considerable economic losses, serious injuries and the loss of human lives. As a consequence, the Energy Performance of Structures Directive [4] stated that Member States should also consider seismic hazards when designing long-term repair programmes for buildings.

Consequently, seismic upgrades for earthquake-prone zones should be included of current building life extension.

Seismic safety has been the primary focus of current seismic design guidelines (e.g. [5]). With this shift in attention to existing buildings' seismic risk, researchers have also suggested, created, or tested numerous strategies for retrofitting these structures to reduce their vulnerability to earthquakes, with the goal of bringing their findings from the lab to practise. Furthermore, seismic regulations and instructions for retrofitting existing structures have just lately been developed (e.g. [6]). Except in certain circumstances, they are not yet required to be used.

In this context, this study attempts to provide a comprehensive assessment of the seismic upgrading strategies that target reinforced concrete (RC) structures, since they comprise the majority of the current building stock. [9] provides a succinct description of all building kinds. Depending on how they "handle" the structure, seismic upgrading procedures may be split into two broad types..

One may begin by focusing on elements (Local measurements) before moving on to those that affect the whole system (Global measures) (Global measures). In order to produce a cost-effective strengthening strategy for a real structure, multiple solutions may and may need to be integrated, addressing its individual features. Seismic intervention techniques may also be categorised into traditional and new ones based on their age and the materials used in each approach.

The aims of a seismic retrofitting strategy are shown in Fig. 1. When just a structure's ductility has to be enhancedMeasures taken at the local level are usually adequate and have little or no effect on the structure's strength and stiffness. Since a result, if the capacity is to be raised, global measures would most likely have to be implemented, as increasing the lateral load capacity of a building by local measures alone would be anuneco-nomical approach. A mix of global and local actions should be used when both the structure's capacity and its flexibility are under jeopardy. The word "capacity" and "strength" are often used interchangeably in this work.

In addition to enhancing the lateral strength of a building, a structure's bulk and/or lateral stiffness may be reduced to reduce the earthquake-induced stresses. The use of lighter partition walls, floor removal, etc., as well as the use of base isolators and energy dissipation systems (e.g. Buckling-restrained bracing, see Section 3.1.1.3), may reduce mass and stiffness, respectively. Table 1 describes the most prevalent measures and the attributes they influence, whereas Fig. 2 depicts the major types of seismic upgrading approaches for RC structures. Following parts of this article will detail certain approaches in detail.

Measures taken in the community

In order to improve a building's mechanical performance, certain structural sections may be upgraded using local upgrading procedures. Reinforcement may be added to an existing beam, column or joint to enhance its flexural and shear strength as well as the flexibility of the structure.

Concrete and steel are used in traditional procedures, but newer methods include fiber-reinforced polymers (FRP), textile-reinforced mortars (TRM), etc. Conventional and unique strategies will be discussed in the following sections, with greater focus on the latter.

Jacketing of RC/mortar

When it comes to seismic upgrading, the first and most common method is to build an RC jacket around an RC component, increasing its sectional area and increasing its longitudinal and transverse reinforcement. The member's flexural and shear capacity, as well as its ductility, may be considerably enhanced by this method. Because the element's bending stiffness rises as a result of its increased dimensions and additional flexural reinforcements, this could not be acceptable in certain instances. There have been many articles on RC jackets of different kinds.

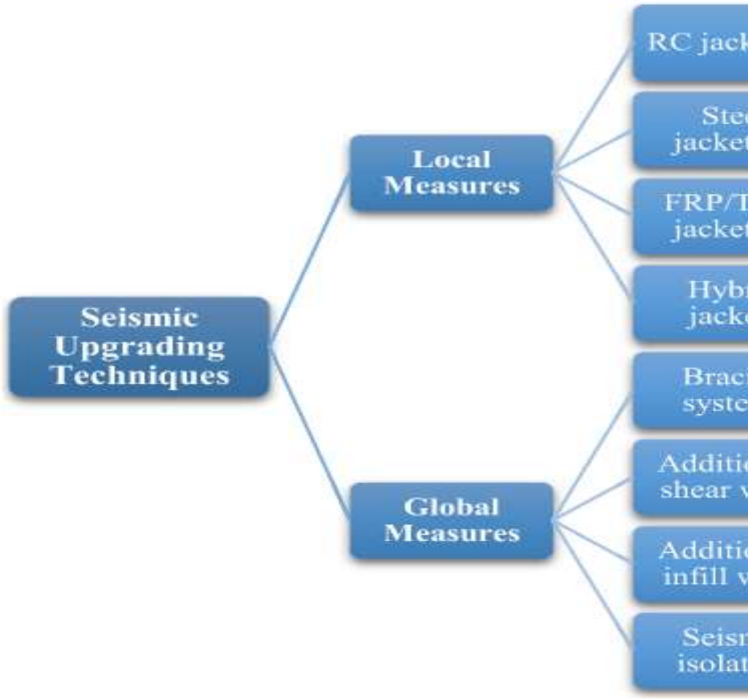


Fig. 2.Taxonomy of seismic upgrading techniques.

There have been a number of studies (e.g. [10–16]) that have been applied effectively in practise recently.The use of high-performance materials in such jackets is on the rise as a result of their greater durability and mechanical qualities. Numerous options are available in this area, and they are outlined here.

Corrosion-damaged RC columns may be strengthened in the crucial zone using HPFRCC (high-performance, fiber-reinforced cementitious composite mortars). The force–displacement behaviour may be improved, energy can be dissipated better, and stiffness degradation can be reduced using such methods [17,18]. UHPFRC has been observed to reduce bond failure and damage in plastic hinge zones in RC columns with inadequate lap slices when used as a self-compacting UHPFRC [19]. Ferro-cement [20] and modified cementiti [21] have been used in other investigations.

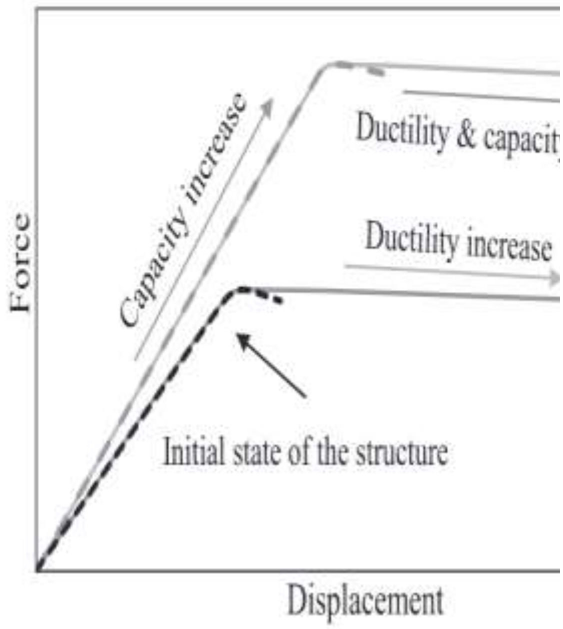


Fig. 1.Seismic retrofitting goals.

Fig. 3. Seismic upgrading with RC jacketing [Source: Courtesy C. Chrysostomou, TUC].

2.2. Steel Jacketing

Structural steel may be utilised as external reinforcement instead of RC or other cementitious materials to improve the performance of current RC components (Fig. 4). The flexural and shear strength, as well as the ductility and stiffness, of an RC element may be improved by forming a cage around it using steel angles and plates [23,24]. Alternatively, parts might be enclosed with tubed steel or steel sheets to provide

Fig. 4.Seismic upgrading with steel jacketing.

enhance the ductility and shear capability of the inner concrete with further confinement [25,26]. Filling the void between the steel and the existing concrete with grout is an option in the latter instance.

Fast repair of severely damaged circular RCC columns has been proposed by Fakharifar et al. utilising lightweight, prestressed steel jackets. The RC element is encased in a thin steel sheet that is held in place by a number of prestressed strands to prevent it from buckling. A two-person crew can complete the retrofitting operation in less than 12 hours and without altering the original column's shape. However, the stiffness of the tested members could only be restored to around 84% of the stiffness of the undamaged column thanks to the method's ability to restore strength and ductility to 115 and 140 percent, respectively.

An new technique to seismic strengthening of rectangular RC columns, which handle extremely high axial loads (normalised axial loads of less than 0.6), was advocated by Wang and colleagues [28]. Anchor bolts are used to tie together pre-cambered steel plates that are placed to the member's opposing sides and then post-compressed. Pre-compression enables a large reduction in axial load on the column by shifting some of it to new steel components. According to the results of this research, it is possible to modify the steel plate thickness and/or the initial pre-camber to optimise the shear-carrying capacity and ductility of the reinforced columns under high axial loads.

The use of steel jacketing methods to upgrade RC components is a less common approach in engineering, but it may nevertheless deliver great results in some circumstances. The following are the most notable advantages and disadvantages of steel jacketing-related methods:

Increase in strength and ductility. + Uses materials known to both engineers and workers.

- Expensive, time-consuming and labor-intensive procedure *.

- Disruption of occupancy *.

- Corrosion protection is required.

Stiffness modification and significant weight increase *.

Although these disadvantages exist, they are not as severe as those of RC jacketing

The FRP jacketing, section 2.3

Fiber-reinforced polymers are widely used in the retrofitting of individual RC components for earthquakes (FRP). Retrofitting with FRP is a great alternative to the more conventional ways since it is fast and easy to install with few modifications to the geometry. It also has a high strength to weight ratio and causes the least amount of interruption to occupants (e.g. [29]). However, when subjected to high temperatures, they display extremely bad behaviour and need high-quality work from trained employees, which necessitates the use of protective gear. While this isn't typical, the great strength of FRP may only be used to 35 percent of its potential in certain applications (such as U-shaped jackets in T-beams) owing to the fact that the debonding failures occur before the material failures in these less common cases. Spiked anchors boost the tensile strength of FRP (see Section 2.3.2).

2.3.1. Types of fibre

Many different kinds of fibres exist within FRP materials. Carbon (CFRP) is the most common fibre type utilised in seismic retrofitting applications owing to its high elastic modulus and outstanding durability, but it is also the most costly. Glass fibres (GFRP) are a more cost-effective option, but they have just a third of the elasticity modulus of carbon fibres, which necessitates the use of more material. Polyethylene terephthalate and polyethylene terephthalate terephthalate (PBO) are other fibres that may be utilised, although they are less popular (PET). Finally, a hybrid FRP may be created by mixing two or more materials. There are many ways for strengthening different kinds of fibre, as seen in the typical stress–strain curves in Figure 5.

2.3.2.1 The Basics. Externally bonded reinforcement (EBR) of RC members is a common application for FRP, which may be employed in two ways. Epoxy resins are used to adhere FRP textiles to concrete substrates (Fig. 6) in the first and most common method. To provide a ductile flexural response, they may be utilised as shear reinforcement in beams and columns with inadequate stirrups. In addition, by being wrapped around columns, they limit the inner concrete, increasing the section's ductility dramatically. In addition to basic cross-section forms (such as circular or rectangular with a low aspect ratio), the use of anchors allows for the application of textiles to more complex cross-section shapes (such as T, L, rectangular with a high aspect ratio).

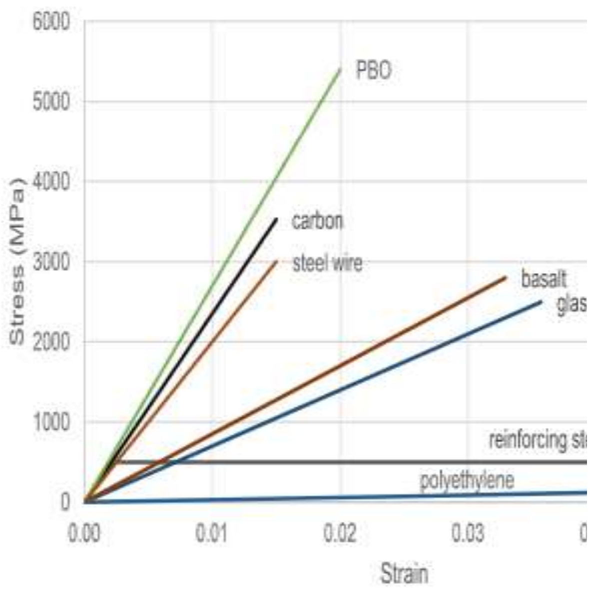
FRPs may also be employed as external longitudinal or transverse reinforcement in existing parts to boost their flexural or shear capacity, although this is unusual in seismic retrofitting (Fig. 7). Near Surface Mounting (NSM) is a way of attaching them to RC members that is both exterior and internal. External flexural reinforcement of reinforced components does increase flexural strength, but deformation capacity decreases due to fibre failure (or debonding) at much lower stresses than reinforcing steel, as should be underlined (e.g. see Fig. 5). Fig. 8 summarises FRP strengthening and retrofitting options. 2.3.2.2. Seismic retrofitting using FRP. Shear reinforcement or further confinement have been shown to be the most successful uses of FRP in seismic retrofitting in the form of sheets. [29] provides an overview of seismic retrofitting of RC with FRP, while [30] and [8] provide more in-depth treatments of the topic. The following are a handful of the many additional studies that have been done.

CFRP wrapped RC columns have stable flexural behaviour, which means that they can endure several loading/unloading cycles with little or no loss of strength. To avoid shear failures and confine the inner concrete portion, they found that the exterior reinforcement performed like traditional steel hoops in their tests. It was also shown that ductility was enhanced, column failure was postponed, and buckling of longitudinal bars could be avoided with the use of stronger CFRP jackets in research by Sause et al. [32], Ghobarah and Galal [33], and Haroun and Elsanadedy [34–35]. Balsamo et al. [36] used a mix of CFRP sheets and laminates to reinforce a full-scale RC structure during a seismic event.

RC members with GFRP jackets have shown similar improvements in seismic performance. The ductility, energy dissipation, and capacity of RC columns, as well as the seismic performance of RC columns with inadequate lap slices, have all been improved by GFRP wrapping, as reported by Sheikh and Yau [37], Memon and Sheikh [38], and Youm et al. [39].

With or without corrosion, researchers Bousias et al. [40] tested the effectiveness of CFRP jacketing against GFRP jacketing on RC columns. The efficiency was determined to be the same regardless of the circumferential stiffness (FRP elasticity modulus times jacket thickness). [41] also came to the same result about stiffness being the deciding factor.

According to Abdel-Mooty et al. [42,43], the most efficient confinement was observed in circular sections, followed by square and finally rectangular cross-sections for the RC components. This



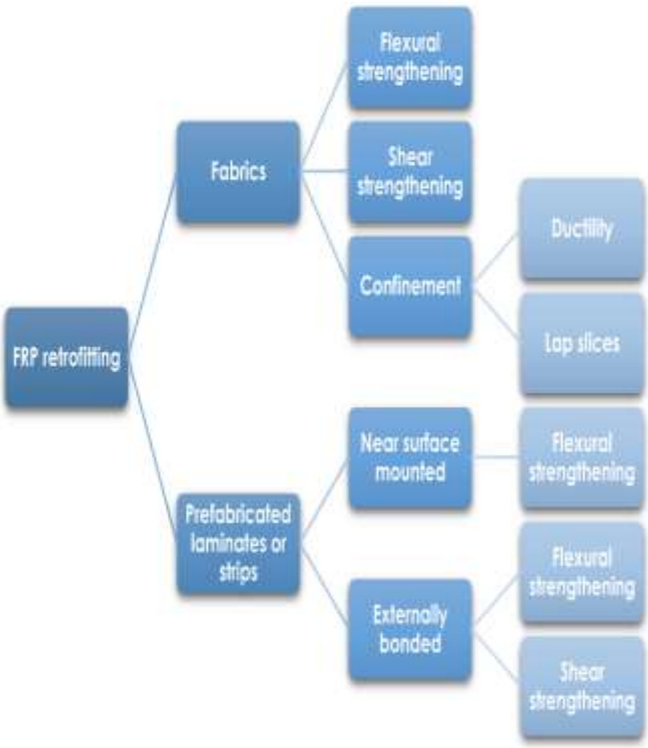


Fig. 8. FRP strengthening roadmap

It has been drastically reduced. FRP wraps have been examined by Colomb et al. [49] who found that the former display flexural failure, whilst the latter showed mixed flexure-shear behaviour.

To improve the seismic performance of existing beam-column joints with poor seismic features, Pantelides et al. [50] demonstrated that CFRP jacketing is an efficient rehabilitation strategy.

To counteract the stress hysteresis of the FRP sheets relative to the inner concrete, prestressing has been used in conjunction with FRP jack-eting, such as in the work of Zhou et al [51]. Overall, there was an increase in seismic performance due to an increase in load capacity, ductility, and energy dissipation.

FRP textiles with externally applied flexural reinforcement for columns were attached to the columns using carbon fibre spike-anchors [52]. The bigger the amount of fibres in an anchor, the greater the tensile strength it can withstand, according to research on anchor effectiveness. It was also studied by Bournas et al. [53] how carbon fibre spike-anchors may link the column flexural (longitudinal) FRP reinforcement to the foundation block. When Pohoryles et al. [54] suggested the use of carbon-fiber strands to reinforce RC columns and eliminate single-storey mechanisms, it was shown to be an effective anchoring method that could be employed in many strengthening applications, including seismic upgrading.

RC columns with and without lap slices were refitted with tensioned GFRP winding wires by Choi et al. [55]. Flexural capacity and drift at failure were improved, but longitudinal reinforcement buckled, concrete spalled, and lap slices split as a result of the ret-rofitting approach.

Full CFRP vs strap CFRP wrapping as external reinforcement in shear-controlled RC columns was recently evaluated in a comparative research by Yang and Wang [56]. Shear capacity and ductility decreased as axial loads rose for the retrofitted column. Full wrap- ping was less efficient than CFRP straps in terms of volumetric ratio. RC columns with higher strengths were also studied by Wang et al. [28] who came up with the same conclusion. Nevertheless, they found that encasing the components completely improved their behaviour and performance.

To compare PET and aramid FRP, Dai et al. used large fracture strain polyethylene terephthalate (PET) FRP (AFRP). They found that PET FRP enhances ductility greatly and does not rupture at the ultimate limit state, making it a viable alternative to conventional FRP in terms of ductility and cost. Recent studies have shown that conventional CFRP is more efficient than PET FRP in the repair of partly corroded columns. According to their findings, PET FRP had comparable seismic performance increase in terms of energy dissipation, damping ratio, hysteretic performance, and stiffness degradation to those of other materials.

It was employed by Chang et al. [13] to improve the structural integrity of weak RC columns. Retrofitted specimens were found to exhibit ductility and greatly enhanced energy dissipation in their investigation.

Ouyang et al. [59] compared BFRP and CFRP on RC columns using basalt FRP (BFRP). They found that BFRP retrofitted columns performed as well as or better than those retrofitted with CFRP, based on their findings. While CFRP sheet costs around five times as much as BFRP sheet, writers found that BFRP sheet is a viable alternative

Conclusion

Seismic upgrading of existing reinforced concrete (RC) buildings has gained a lot of attention in the academic community and engineering practise, as well as EU initiatives (European Green Deal, Renovation Wave) that favour an integrated retrofitting strategy (e.g., seismic and energy). For RC structures, unique methodologies have been devised to improve their seismic performance, which was the focus of this article. Discussion and evaluation of the benefits and drawbacks of regional and global approaches were also included.

When lateral strength and stiffness are already adequate, local retrofitting methods are often used.

There are several ways to increase the shear strength of RC beams and columns, but the most frequent is the installation of a jacket. The innovative (FRP and TRM) jacketing materials were studied more than the old (concrete and steel). FRP, in particular, has been employed effectively in a number of experimental and real-world projects. In contrast to RC and steel jackets, they are also corrosion-free and do not alter the size or rigidity of the components. Although their poor conduct at high temperatures necessitates additional fire protection precautions. As a jacketing material, TRM has promise as an alternative to FRP. But they're more environmentally friendly, simple to set up, and offer better fire resistance.

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