Retrofitting of Concrete Structures: A Review

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Abstract - *Given the age and continued deterioration of infrastructure, upgrading concrete structures has gained importance. Because of improved construction methods, the issue is worse. A structural engineer faces a dilemma when deciding whether expansion procedures or materials are best for retrofitting a structure. Retrofitting is the science and technology of enhancing the performance of existing structures or structural components with new technologies, features, and components. A reinforced concrete structure that has already been built can be retrofitted by making repairs, rehabilitations, or strengthening. The current article explores the comprehensive study of retrofitting along with its classification. Moreover, the necessity and importance of the retrofitting accompanying the procedure of the same are explained. In addition, the various methodologies of retrofitting the retrofitting of reinforced concrete structures are explained in the present article.*

***Key Words*:** Retrofitting, Concrete Structure, Repair, Buildings, deterioration.

1.INTRODUCTION

In the current situation, concrete structure deterioration is an international issue. Numerous factors contribute to this, including the occurrence of natural disasters like earthquakes, a lack of awareness of various crucial statutory requirements in the field of building, inadequate oversight, etc. These elements cause constructions to lack strength. Structure overloading can occasionally result in extreme deformations and corrosion, both of which demand today's attention. Today's building industry often calls for strengthening, retrofitting, and repair work to counteract all these effects on reinforced concrete structures [1, 2].

All of these potential ways to produce damage will call for a range of potential repair methods, from which the most efficient one will be selected in each specific situation. In some circumstances, even recently constructed structures need to be repaired and strengthened in order to remove flaws caused by mistakes in the design or construction. It has always been highly difficult to repair a concrete structure or one of its components, and effective solutions frequently required substantial work [3]. To deal with structural elements damaged by unexpected events like fire, earthquake, foundation movement, impact, and overload, specialized procedures of strengthening, stiffening, and repair are required [4].

Numerous existing bridges, industrial buildings, urban transportation hubs, marine structures, and earth-retaining structures require maintenance or improvement. The reinforced concrete constructions must undergo some alterations and advancements during their service life for a variety of reasons. Retrofitting or replacement are the two options available in this situation. Whole structures must be replaced, which has drawbacks including expensive labour and material prices. Therefore, if possible and practical, it is preferable to repair or update the structure rather than replace the entire thing [5].

2.RETROFITTING

Retrofitting is the process of giving anything a component or feature that was not included during manufacture or by adding something that was not present at the time of original construction. It frequently refers to the installation of new building systems, such as heating systems, but it may also apply to the fabric of a building, like installing double glazing or retrofitting insulation. Retrofitting RCC structural members are done to restore the strength of the weakened concrete element structure [6]. Additionally, it aids in halting additional damage to concrete components. Errors in the design or subpar construction could be to blame for the concrete element's lack of strength. Another explanation for the decline can also exist, such as the aggressiveness of dangerous substances [7].

Depending entirely on the extent of the damage caused, the required capacity of the structure may be restored once the right method of retrofitting is applied and specified. Numerous methods, including external plate bonding, grouting, external post-tensioning, section enlargement, and fibre-reinforced polymer composites, are employed during the retrofitting process [8]. When structures and engineering projects get damaged to the point that they cannot be used for general purposes, they may require strengthening and repair. Such situations. The risk of lives being lost as well as any structural and content damage would be intolerable since the structure cannot sustain a subsequent sequence of the same action or other unintentional acts with acceptable reliability. Retrofitting is a strengthening modification that can restore a suitable level of safety and defence against such acts [9].

Retrofitting is classified into two ways i.e., (1) Local Retrofitting and (2) Global Retrofitting. The seismic resistance of the structures is the focus of the global retrofitting technique. Shear structure addition, steel bracing addition, infill structure addition, and foundation isolation are all part of it. Flat slabs or flat plates can be used to add shear structures into a construction. With the least amount of interference to the building's function, they can be given in the outer frames [10]. A local retrofitting technique focuses on a member's seismic resistance. The local retrofit technique involves jacketing structural members, such as beams, columns, foundations, and beam-column joints, with concrete, steel, or fibre-reinforced polymer. By adding a fresh layer of concrete with longitudinal reinforcement and evenly spaced links, concrete jacketing is accomplished. The jacket improves the column's or the beam's flexural strength in both directions [11].

2.1 Importance and Need

Retrofitting is now spreading uncontrollably over the globe as a substantial portion of recorded, public, and private noteworthy designs get old and weaken with the passage of time. Retrofitting is likely the best option for securing a weak structure against potential threats or other natural forces. Retrofitting is the process of adding new features to older structures, legacy structures, spans, and so forth [12]. Retrofitting reduces the potential for injury from an existing design during an impending seismic event. It is the modification of current designs to make them more resistant to seismic activity, ground movement, and soil disappointment produced by seismic tremors or other typical cataclysms, such as twisters, typhoons, and winds with high velocity generated by tempest, blizzards, and hailstorms. Several designs have historical, social, or public significance. Strength and resistivity are improved through retrofitting [13].

As time goes on, the structure is impacted by a variety of environmental conditions. The most harmful of these is an earthquake, which disrupts the interior structure of the building and gradually causes that structure to lose its strength and stability [14]. As a result, the building is rendered dangerous for usage in the future and could result in a significant loss. The concrete element structure's level of deterioration is progressing at an alarming rate. It has been confirmed that there is a high probability of concrete element deterioration and reinforcement corrosion even when every precise construction code is followed [15].

One of the major factors that contribute to the deterioration of reinforced concrete components is steel corrosion, which may lead to cracking, a reduction in the reinforcement's useful area, spalling of the concrete's top layer, and even collapse. When dealing with damages, there are many different situations [16]. If a building, whether it be in the public or private sectors, such as an office or a home, suffers severe structural damage. Civil engineers prefer to tear down and rebuild the structure [17]. However, dismantling significant or historically significant buildings is not an option. In the effort to make buildings more efficient and practical, retrofitting has taken centre stage. By reducing fossil fuel waste, lowering operating costs and making structures easier to maintain, as well as helping to combat helpless ventilation and moisture problems, the overall situation will be improved. Additionally, it can increase a building's robustness, flexibility, and adaptability [18].

2.2 Retrofitting Process

The primary goal of retrofitting or repair work is to raise the load-bearing capacity, boost the structure's performance, or prolong its useful life. The sensible approach to any retrofitting operation is to take into account both the root cause and the symptoms of the degradation. Without a thorough grasp of the root causes of the issues, fixing only the symptoms can result in hidden flaws being discovered beneath the finished product. Repair of the retrofitting work is believed to be something that should be avoided, so the following actions should be taken [19-21].

- Determine the performance criteria for the existing structure that has to be retrofitted and create a comprehensive plan that includes inspection, technique selection, structural design, and implementation of the retrofitting work.
- Examine the structure that needs to be retrofitted.
- Assess the structure's performance based on the inspection's findings, and make sure it complies with the performance standards.
- Design of the retrofitting structure should be done if the structure does not meet performance standards and if it is desirable to keep using the structure after the retrofit.
- Determine the materials to be utilized, the structural specifications, and the construction technique, then choose the best retrofitting strategy.
- Analyze the structure's performance following the refit and ensure that it satisfies the performance standards.
- Implement the retrofitting work if it is assessed that the retrofitting structure will be able to satisfy performance requirements using the chosen retrofitting and construction methods.

3. METHODS OF RETROFITTING OF REINFORCED CONCRETE STRUCTURES

3.1 Concrete Jacketing

Concrete jacketing is one type of retrofit for the beams. To increase the flexural and/or shear capacity, extra longitudinal bars and stirrups must be added together with an additional layer of concrete around the current beam. The inquiry on reinforcing beams with bottom bars that are interrupted at joints is described in the current work. Concrete jacketing is required to increase bearing load capacity after a structural design revision or to restore structural design integrity following a structural member failure. This method is applied on vertical surfaces like walls, columns, and other combinations like the bottom and sides of beams. Figure 1 demonstrates the concrete jacketing [22].

Fig -1: Concrete Jacketing

3.2 CFRP Jacketing

Many constructions found in seismically active zones are not able to withstand seismic waves, according to Indian Standard code requirements for earthquake concerns. Additionally, due to inadequate design, poor construction, additional loads, increased performance demands, etc., the seismic behaviour of existing structures is impacted. Recent earthquakes have revealed that the shear failure of beam-column joints is the main factor in the collapse of many moment-resisting frame buildings. Numerous research projects have been conducted to create various strengthening and restoration approaches to enhance the seismic performance of existing structures. Figure 2 depicts the CFRP jacketing [23].

Fig -2: CFRP Jacketing

In the event of future seismic activity, A structure's susceptibility to harm is decreased by retrofitting. In order to meet the requirements of the present codal provisions for seismic design, it seeks to strengthen a structure. In recent years, it has been discovered that seismic retrofit with FRP materials has gained noticeably acceptance among the various retrofitting methods. FRP material retrofitting is a technically sound and economical repair technology that is currently widely employed as a seismic retrofitting approach. The options and procedures used in practice for wrapping the beam-column joints have been reviewed in this study. The breadth and applications of FRP materials like carbon fibre reinforced polymer (CFRP) and glass fibre reinforced polymer are also summarized in this study (GFRP) [24, 25].

3.3 Steel Jacketing

Increases in basic strength capacity can also be achieved by the use of steel jacketing. Steel jacketing not only offers adequate confinement but also stops shell concrete deterioration, which is the primary cause of bond failure and longitudinal bar buckling. Steel jacketing is the process of covering a part with steel plates and filling the space with grout that won't shrink. It is a very efficient way to fix flaws like insufficient shear strength and poor longitudinal bar splices at crucial points. But it could be expensive, and you have to think about how fire resistant it is. Steel strips and angles are the most widely utilized reinforcing method in real life. Steel jacketing appears to be useful for retrofitting columns since it helps to restore the strength, ductility, and energy absorption capacity of columns. Additionally, the steel jacket contributes to the lap-spliced column's increased flexural strength and ductile behaviour, improving the lateral performance of columns. Figure 3 shows the basic steel jacketing of the concrete structure [26].

Fig -3: Steel Jacketing

3.4 Steel Caging

Figure 4 demonstrated the steel caging of the structure. To improve the total energy dissipation potential and lateral stiffness, a strengthening technique using steel caging is proposed to raise the lateral strength of weak ground-storey columns. This will also improve the seismic performance of non-ductile open-ground-storey RC frames. With the aim of having the structure generate enough flexural strength and inelastic rotation at a target yield mechanism to survive the likely seismic demand, a performance-based design methodology was developed [27].

Fig. -4: Steel caging

4. LITERATURE REVIEW

The author [28] carried out an experimental study by externally bonding GFRP sheets to the RC beam and testing under the two-point static loading system. The study is based on the flexural behaviour of RC beams wrapped with GFRP sheets. Six reinforced concrete beams were made for this, and it was found that all six of them had the same reinforcement details and were weak in flexural loads. The bottom of the GFRP sheet wrapping in a 70% preloaded beam can increase the flexural capacity of the beam by 14% (on ultimate load) in comparison to the control beam, the researchers found. They separated three beams, used three as control beams, and strengthened the other three using GFRP in the tension zone.

Using rubberized fibre sheets tested under two-point loads, the authors [29] undertook experimental work on the retrofitting of reinforced concrete beams. The goal of this experiment was to repair structurally flawed beams and make them usable in both flexure and shear. Additionally, they make the modifications so order to guarantee that the stiffness and strength values are higher than those of the control beam. Values for the parameters are higher than those for the control beams. First crack, load deflection, and RCFS debonding were the metrics that this study's researchers discovered, along with patterns of fracture propagation. To increase shear strength and strengthen at the same time, they used shear straps. The test findings revealed that the retrofitted RCFS beams have significantly higher stiffness than the control beams, and their deflection is significantly decreased early in the loading cycle. There is a rise in the ultimate loads upon failure.

In order to strengthen the reinforced concrete beam (RC) against flexure, the author [30] investigated the potential use of externally bonded hybrid fibre reinforced polymer (HYFRP) with a combination of glass (GFRP) and carbon (CFRP)based laminates. To evaluate the flexure strength, a total of five beams with cross sections measuring 150 mm by 250 mm by 3000 mm long and 2800 mm simply supported span were cast. Five beams were used, one of which acted as a reference beam. The other four were composed of hybrid FRP laminates, with the parameters measured being stirrup spacing, HYFRP laminate thickness, and composite ratio. The test findings demonstrated that the RC beam reinforced with hybrid fibre reinforced polymer (HYFRP) exhibited enhanced strength and composite action up until failure.

The author conducted a study on reinforced concrete beam failure behaviour in 2015 [31]. strengthened with a brand-new type of wire mesh-epoxy composite reinforcing material. Additionally, it was contrasted with an RC beam reinforced with a CFRP sheet (carbon fibre reinforced polymer). The test results revealed that using a wire mesh-epoxy composite improved the stiffness, yield strength, and first crack load of reinforced beams. In addition, using a hybrid wire mesh-epoxy-carbon fibre composite resulted in better post-yield behaviour and reduced the risk of CFRP sheets coming loose during the yielding process.

According to a study [32], the flexural behaviour of reinforced concrete beams with multi-directional basalt fibre-reinforced polymer composites. By externally reinforcing the concrete beams, the research discusses an experimental behaviour of the basalt fibre reinforced polymer composite. At the bottom face of the RC beam, the BFRP composite is wrapped in one, two, three, and four layers. Based on the results of this experiment, the first fracture load is increased from 6.79 to 47.98 percent depending on the increment in layers. The maximum load carrying capacity has also been raised from 5.66 to 20 percent. The crack spacing likewise decreases as the number of layers rises. The majority of the reinforced beams in unidirectional BFRP displayed compression and flexure cum crushing modes. The number of layers is increased, which increases the beams' stiffness. By expanding the basalt fibre layers, the curvature of strengthened beams is also reduced. The number of cracks increases while crack spacing decreases due to an increase in basalt fibre layers.

The study titled "Comparative evaluation of different retrofitting strategies" is examined by the author [33]. For a very long time, concrete has been a significant and productive material in the construction sector. It is used in the building industry in a wide variety of ways. From this experiment, all beams were retrofitted utilizing various procedures, including HFRC, FRC, SIFCON, SIMCON, and Ferro cement. Apply mortar to the full beam after covering the entire beam with SIMCON. Apply mortar- and slurry-infiltrated fibre concrete (steel fibre) to the surface of beams. The same procedure will be used for polypropylene fibre. In Ferro cement retrofitting, chicken mesh and welded wire are utilized to cover the beams before the surfaces are covered with mortar. As a result, it can be said that the concrete beam retrofitted with SIFCON yields higher flexural strength, with the percentage in the flexural strength as compared to the beam without retrofitting being found to be 85.03 percent. The concrete beam retrofitted with Ferro cement also yields higher flexural strength.

RC beams retrofitted in flexure and shear by pre-tensioned steel ribbons were the subject of an experimental examination by the authors [34]. According to this inquiry, the pre-stressed stainless steel ribbon serves as an auxiliary transversal reinforcement and encloses the structural element. Nine shear deficient beams and six flexural deficient beams were cast and tested in the current study. In the first group, four beams were retrofitted with transversal ribbons and bottom stainless steel angles spaced at two different intervals, while in the second group, three specimens were retrofitted by wrapping the beam with ribbons, and the remaining three specimens were strengthened by perforating the beam beneath the slab height and by partially wrapping the beam by putting the ribbons through the hole. It was determined that the test results demonstrated the effectiveness of the method.

The study [35] investigated the use of external bars at the soffit level to retrofit RC beams for flexural loads. In an experimental investigation, the authors suggested that the exterior bars be retained at the beam section's soffit level to avoid the need for mechanical anchoring devices like deflectors and make the design more practical, straightforward, and efficient. The improved ductility decreased deflection and fracture width, and increased moment bearing capacity of the current method are further benefits. The inherent drawbacks of existing retrofitting techniques, such as section enlargement, bonded steel plating, external post-tensioning strengthening, and strengthening with FRP composite sheets, include high coast, the need for sophisticated tools, an increase in sectional area, and surface preparation. De-bonding failures, a poor cost-benefit ratio, costly maintenance, etc. The suggested method of maintaining reinforcement externally at the soffit level has various benefits, including simple and quick execution, no installation disruption, a low self-weight need, and no discernible reduction in headroom [36].

5.CONCLUSION

For the purpose of finding more effective sustainable retrofitting approaches, new techniques are being developed. The most popular methods are those that were just stated. The retrofitting of a structure affects how that structure responds to risks other than those related to flooding, such as wind hazards, and the architect, engineer, or code official must be aware of this. When it is possible, dangers should be approached holistically. The retrofitting process should take into account both flood-related and non-flood-related risks, such as earthquake and wind forces, as well as water-borne ice and debris impact forces, erosion forces, and mudslide impacts. A structure's ability to endure the several risks outlined above may be harmed by retrofitting it to simply withstand floodwater-generated stresses. As a result, it's crucial to use a multi-hazard strategy while choosing a retrofitting method and designing the project.

REFERENCES

[1] National Institute of Statistics (ISTAT) 16° Censimento Generale della Popolazione e delle Abitazioni. ISTAT; Rome, Italy: 2021. (In Italian)

[2] Dall'Asta A., Landolfo R., Salvatore W. Edifici Monopiano in Acciaio ad Uso Industriale. Dario Flaccovio Editore; Palermo, Italy: 2022. (In Italian)

[3] CNR (Consiglio Nazionale delle Ricerche) CNR-UNI 10011: Steel Structure–Instruction for Design, Construction, Testing and Maintenance. UNI; Milano, Italy: 1988. (In Italian)

[4] CS.LL.PP. (Consiglio Nazionale dei Lavori Pubblici) Criteri Generali per la Verifica di Sicurezza delle Costruzioni e Norme Tecniche per i Carichi ed i Sovraccarichi. Gazzetta Ufficiale della Repubblica Italiana, Italian Ministry for Infrastructures and Transportations; Rome, Italy: 1982. (In Italian)

[5] CS.LL.PP. (Consiglio Nazionale dei Lavori Pubblici) Circ. 24/05/1982, n. 22631: Istruzioni Relative ai Carichi, ai Sovraccarichi ed ai Criteri Generali per la Verifica di Sicurezza delle Costruzioni. Gazzetta Ufficiale della Repubblica Italiana, Italian Ministry for Infrastructures and Transportations; Rome, Italy: 1982.

[6] CS.LL.PP. (Consiglio Nazionale dei Lavori Pubblici) D.M.24/01/1986: Norme Tecniche per le

Costruzioni in Zone Sismichel. Gazzetta Ufficiale della Repubblica Italiana, Italian Ministry for Infrastructures and Transportations; Rome, Italy: 1986.

[7] Cantisani G., Della Corte G. Modelling and Seismic Response Analysis of Non-residential Existing Steel Buildings in Italy. J. Earthq. Eng. 2022 doi: 10.1080/13632469.2022.2030438.

[8] Scozzese F., Terracciano G., Zona A., Della Corte G., Dall'Asta A., Landolfo R. Modelling and seismic response analysis of Italian code-conforming single-storey steel buildings. J. Earthq. Eng. 2018;22:2104–2133. doi: 10.1080/13632469.2018.1528913.

[9] Simões da Silva L., Silva L.C., Tankova T., Craveiro H.D., Simões R., Costa R., D'Aniello M., Landolfo R. Performance of modular hybrid cold-formed/tubular structural system. Structures. 2021;30:1006–1019. doi: 10.1016/j.istruc.2021.01.066.

[10] Poursadrollah A., D'Aniello M., De Martino A., Landolfo R. Preliminary study on the seismic performance of hybrid steel structures with truss lightweight girders and plug-and-play connections. Ing. Sismica. 2020;37:102–114.

[11] Faggiano B., Formisano A., D'Aniello M., Landolfo R. Steel Constructions in the Framework of the Emilia-Romagna Earthquake. Progett. Sismica. 2012;3:189–200. (In Italian)

[12] Braga F., Gigliotti R., Monti G., Morelli F., Nuti C., Salvatore W., Vanzi I. Speedup of post earthquake community recovery: The case of precast industrial buildings after the Emilia 2012 earthquake. Bull. Earthq. Eng. 2014;12:2405–2418. doi: 10.1007/s10518-014-9583-3.

[13] Formisano A., Di Lorenzo G., Iannuzzi I., Landolfo R. Seismic Vulnerability and Fragility of Existing Italian Industrial Steel Buildings. Open Civ. Eng. J. 2017;11:1122–1137. doi: 10.2174/1874149501711011122.

[14] Di Sarno L., Freddi F., D'Aniello M., Kwon O.-S., Wu J.-R., Gutiérrez-Urzúa F., Landolfo R., Park J., Palios X., Strepelias E. Assessment of existing steel frames: Numerical study, pseudo-dynamic testing and influence of masonry infills. J. Constr. Steel Res. 2021;185:106873. doi: 10.1016/j.jcsr.2021.106873

[15] Romano E., Cascini L., D'Aniello M., Portioli F., Landolfo R. A simplified multi-performance approach to life-cycle assessment of steel structures. Structures. 2020;27:371–382. doi: 10.1016/j.istruc.2020.05.053

[16] Kazantzi A.K., Vamvatsikos D. Seismic and Vibration Performance Rehabilitation for an Industrial Steel Building. Pract. Period. Struct. Des. Constr. 2020;25:05020001. doi: 10.1061/(ASCE)SC.1943-5576.0000475.

[17] Di Sarno L., Elnashai A. Bracing systems for seismic retrofitting of steel frames. J. Constr. Steel Res. 2009;65:452–465. doi: 10.1016/j.jcsr.2008.02.013.

[18] Rinaldin G., Fasan M., Sancin L., Amadio C. On the behaviour of steel CBF for industrial buildings subjected to seismic sequences. Structures. 2020;28:2175–2187. doi: 10.1016/j.istruc.2020.10.050.

[19] Formisano A., Di Lorenzo G., Landolfo R. Seismic retrofitting of industrial steel buildings hit by the 2012 Emilia-Romagna earthquake: A case study. AIP Conf. Proc. 2019;2116:260021. doi: 10.1063/1.5114272.

[20] Hirde S., Jagtap M. Retrofitting of Damaged Industrial Buildings. Int. J. Civ. Eng. Technol. 2013;4:267–277.

[21] Bournas D.A., Negro P., Taucer F.F. Performance of industrial buildings during the Emilia earthquakes in Northern Italy and recommendations for their strengthening. Bull. Earthq. Eng. 2013;12:2383–2404. doi: 10.1007/s10518-013-9466-z.

[22] CEN (European Committee for Normalization) EN1993:1-1 Eurocode 3: Design of Steel Structures–Part 1-1: General Rules and Rules for Buildings. CEN; Bruxelles, Belgium: 2005.

[23] Xu Z.-D., Liao Y.X., Ge T., Xu C. Experimental and Theoretical Study of Viscoelastic Dampers with Different Matrix Rubbers. J. Eng. Mech. 2016;142:04016051. doi: 10.1061/(ASCE)EM.1943-7889.0001101.

[24] Reitherman, Robert, Earthquakes and Engineers, International History, Reston, VA, 2012, ASCE, press, pp. 486-487.

[25] Silva M A L, Dedigamuwa K V and Gamage J G P H 2020 Performance of severly damaged reinforced concrete flat slab-column connections strengthened with CFRP

[26] Suhreed Das, Farjana Akter, Farzana Rahman Chowdhury and Jobaidul Alam Boni 2016 Retrofitting of Flat Slab Building Members Undergone Damage by Earthquake Forces – Asian journal of innovative research in science, Engg. and Tech. 5

[27] Marco Valente 2012 Seismic rehabilitation of a three-storey R/C flat-slab prototype structure using different techniques – Applied mechanics and materials 7

[28] Xiangguo Wu, Shiyan Yu, Shicheng Xue, Thomas H.-K. Kang and Hyeon-Jong Hwang 2019 Punching shear strength of UHPFRC-RC composite flat plates

[29] Graziano Salvalai, Marta Maria Sesana and Giuliana Iannaccone 2017 Deep renovation of multi-storey multi-owner existing residentialbuildings: A pilot case study in Italy

[30] Mary Beth D Hueste and Jong Wha-Bai 2006 Seismic retrofit of a reinforced concrete flatslab structure: Part I – Seismic performance evaluation

[31] Navarro M, Ivorra S and Varona F B 2020 Parametric finite element analysis of punching shear behhaviour of RC slabs reinforced with bolts

[32] Tartaglia R., D'Aniello M., Landolfo R. The influence of rib stiffeners on the response of extended end-plate joints. J. Constr. Steel Res. 2018;148:669–690. doi: 10.1016/j.jcsr.2018.06.025.

[33] 39. Tartaglia R., D'Aniello M., Rassati G.A., Swanson J.A., Landolfo R. Full strength extended stiffened end-plate joints: AISC vs recent European design criteria. Eng. Struct. 2018;159:155–171. doi: 10.1016/j.engstruct.2017.12.053.

[34] 40. Tartaglia R., Milone A., D'Aniello M., Landolfo R. Retrofit of non-code conforming moment resisting beam-to-column joints: A case study. J. Constr. Steel Res. 2021;189:107095. doi: 10.1016/j.jcsr.2021.107095.

[35] 41. Tartaglia R., D'Aniello M., Wald F. Behaviour of seismically damaged extended stiffened end-plate joints at elevated temperature. Eng. Struct. 2021;247:113193. doi: 10.1016/j.engstruct.2021.113193.

[36] 42. Dutta A., Dhar S., Acharyya S.K. Material characterization of SS 316 in low-cycle fatigue loading. J. Mater. Sci. 2010;45:1782–1789. doi: 10.1007/s10853-009-4155-7.