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Evaluating the Performance of Oversize Threaded Splices with Cyclic Loading Protocol:Experimental study

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Abstract

This study aims to evaluate the performance of threaded splices utilizing the oversize method under cyclic loading conditions. Experimental tests were conducted on threaded couplers with enlarged thread diameters to investigate their strength, ductility, and energy absorption characteristics. The results revealed that the oversize-threaded splices exhibited enhanced performance, with reduced stress levels and minimal slippage observed during cyclic loading. The enlarged cross-sectional area near the threads contributed to improved ductility and energy absorption capacity. Moreover, the oversize splices demonstrated a higher ultimate tensile load capacity compared to conventional splices. These findings underscore the effectiveness of the oversize method in enhancing the performance of threaded splices under cyclic loading, rendering them suitable for applications in seismic regions. The outcomes of this study provide valuable insights for designing robust and resilient threaded splices in seismic-resistant structures, contributing to the advancement of construction practices in earthquake-prone areas.

Keywords*:* Mechanical threaded splice, Ductile Members, Cold rolling, Modifying threaded

1. Introduction

Researchers are primarily concerned with the impact of bar splice techniques on seismic activity, overall construction costs and time, and reinforced concrete (RC) structures. It is inevitable for RC structures to have bar splicing because of the limitations on bar length [1–5]. Overlapping bars, couplers, mechanical patching, and head-to-head welding bars are a few techniques for joining reinforcement bars. When the overlapping procedure is used, the length of the overlapping bars must match or exceed the length of the anchorage bar [6]. When ductile detailing is required, the reinforcement congestion becomes particularly significant [7,8]. Because of stress localization at both ends of the lap, conventional lap splices may result in section over-reinforcement, which could change the capacity for deformation and possibly cause a non-ductile reaction in the spliced region. The main issue with this method is that it is not cost-effective, particularly when used on bars larger than 16 mm in diameter. Couplers have therefore become widely used, which not only helps to minimize bar congestion, reduce bar weight, and contribute to cost-effective construction, but also makes the process quicker and easier to implement [1–3,9]. More importantly, the strength of the concrete has a major impact on the performance of lap splices. This means that low-strength concrete may cause the lap splice to fail, even if it is precisely designed and executed[10–13]. Welding under gas pressure (GPW),This method's main advantages are its applicability to medium- to large-diameter bars, its speed and affordability, and the splices it produces exhibit acceptable behavior. Keep in mind that the operator's abilities play a major role in this approach's effectiveness, so the cost and time needed to operate this splice may be similar to those of a mechanical splice [1,14]. Couplers are stiff parts used in the mechanical splice method that connect reinforcement bars [2]. Through the coupler and its components, tensile stress in a mechanically spliced bar is transferred from one bar to the other [8]. Using mechanical methods has the advantages of quick installation, environmentally friendly application, and acceptable performance [2,7,8,15–17]. Currently, there are several standards available for mechanical bar splice testing [18–20]. Nevertheless, neither of these documents specifies modeling techniques or

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approval requirements for couplers to be used in the crucial area of ductile members [7]. In recent experimental research, coupler efficiency was investigated, typically using one or more coupler forms per study[1,14,21–25], and the effect of some couplers on seismic column performance was investigated[8]. Bar couplers are categorized as Type 1 or Type 2 by ACI 318 [26]. This classification is based on the strength that a coupler can produce. A Type 1 coupler, for example, is designed to withstand a force greater than 1.25 times the yield strength of the splicing bar. Caltrans SDC classifies "Service" and "Ultimate" couplers based on their strain capacity [9,27]. Couplers can only be used if they can develop a minimum strength of 1.25 times the yield strength of the bar, according to AASHTO [28]. According to the EC8 [29], the use of mechanical couplers for splicing reinforcing bar in the inelastic deformation zones brought on by earthquakes must be tested to ensure that the conditions are consistent with the ductility class that is selected (i.e. medium ductility: DCM, or high ductility: DCH). Current bridge and building design regulations prohibit the use of mechanical bar splices in the plastic hinge regions of ductile elements in high seismic zones, although couplers are normally permitted [27,28,30]. Three types of studies have been conducted on the performance of mechanical splices: (a) application (both with concrete), (b) applied load (cyclic or monotonic), and (c) loading rate. The same conclusion has been drawn from each study: under cyclic load, splicing all the bars in one area may result in poor behavior. Mechanically spliced steel bars may fail in the coupler or in the bond connecting the coupler and the bar [1,2,7,8,15]. The couplers' brittle material may have contributed to the first type of failure. Here, monotonic or cyclic loads applied to the spliced bars cause the couplers to break and fail. Inadequate preparation of the bars or sleeves leads to the second kind of failure. Certain factors, like thread depth and length in both bars and sleeves (in threaded couplers), insufficient pressure and bar-sleeve lock (in swaged couplers), and the use of the wrong screws in shear screw couplers, can result in bond failure [1–3,7,15,25,31,32]. The studies' authors think that the sleeve geometry (diameter, length, and thread) and embedded length are the most useful parameters for grouted splices. By boosting the bond capacity, an embedded length of 6 db and a sleeve length of 16 db might result in performance that is acceptable [2,3,8]. The structure of the paper is as follows: One kind of patch that can be used in the plastic hinge areas of ductile members in seismic areas can be introduced by altering the procedure for making a mechanical bar splice. The recommended method's splice area is too large. One method is to roll cold to increase the splice area. In this study, non-spliced (NS) reference specimens and threaded couplers (TC) and oversize-threaded couplers (OTC) with reinforcement bar diameters of 16 mm and 20 mm are subjected to uniaxial tensile and cyclic concrete testing. Evaluations were conducted on failure mode performance, strength, ductility, and energy absorption. This article also offers a comprehensive explanation for practical use of the seismic criteria for the bar splices based on different design standards.

2. Experimental Program

The study examined the threaded couplers' behavior under both uniaxial and cyclic loading. Threaded couplers connecting various configurations of steel bars were subjected to monotonic static tensile, tension, and compression tests in concrete. The University of IIEES, or the International Institute of Earthquake Engineering and Seismology in Tehran, Iran, hosted the tests in its Structures Laboratory. employing the 600 kN maximum static capacity and 500 kN maximum dynamic capacity of the Instron Universal Testing Machine (UTM). The goal was to assess the spliced bars' tensile and cyclic behavior, pinpoint the reason behind the failure, alter the mechanical bar splicing process and combine it with rotary friction welding (two types of patches are introduced that can be used in the plastic hinge areas of ductile members in seismic areas), and use an analytical model to predict the threaded splices' final tensile strength while accounting for threaded couplers. These models come in handy when designing threaded coupler-equipped RC columns with plastic hinge regions.

2.1. Specimen Details

Taking into account the practical requirements of the plastic hinge areas of ductile members in seismic areas, a total of 18 specimens were prepared for the tensile loads and cyclic loads. Two varieties of tension-compression couplers with diameter 20 mm, respectively, were chosen for a thorough evaluation (as shown in **Fig. 1**), along with non-spliced (NS) reference specimens. The coupler types are threaded couplers (TC) and oversize-threaded couplers (OTC). The specimen's details are displayed in **Table 1** and **Fig. 1.**

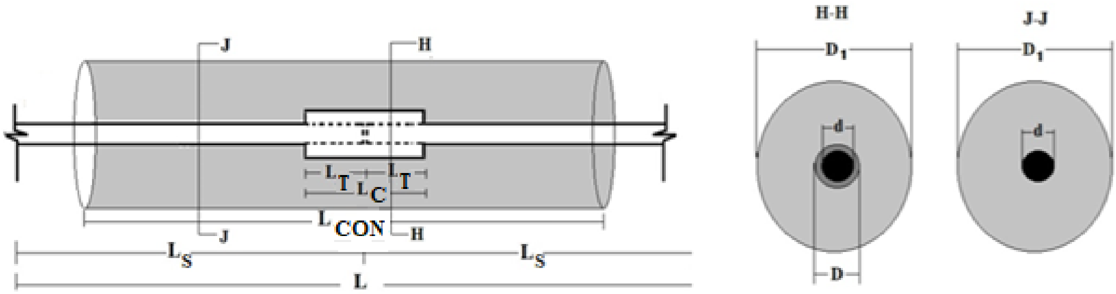


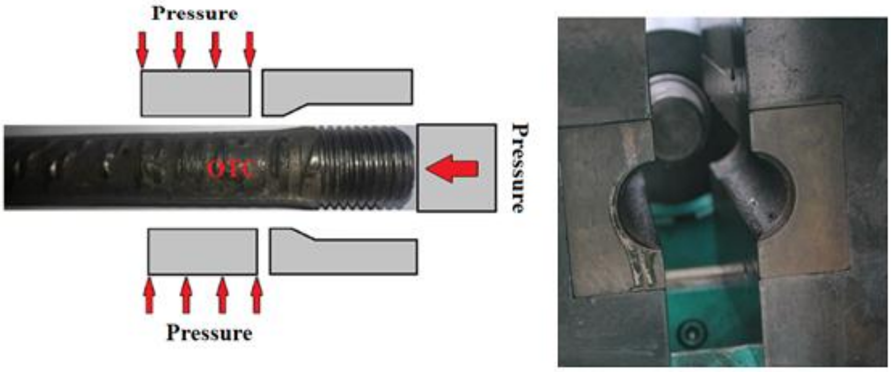
Fig. 1. Details of threaded coupler specimens for TC, OTC, and RFWTC with concrete.

Table 1
Details of test specimens.

Specimen	d_b (mm)	L (mm)	L_S (mm)	L_C (mm)	L_{Con} (mm)	D (mm)	D_1 (mm)
Non-spliced	16	700	-	-	600	-	121
(NS)	20	700	-	-	600	-	151
Threaded	16	700	350	42	600	23	121
couplers (TC)	20	700	350	50	600	30	151
Oversize-threaded	16	700	350	46	600	28	121
coupler (OTC)	20	700	360	54	600	33	151

2.2. Construction and Materials

The OTC specimens were made using a unique cold rolling technique; the machine put hydraulic pressure on the rebar first. A one-size increase in threading size for each rebar is possible thanks to the larger, newly designed thread area. For example, following oversizing, a 20-rebar will have a 22-thread (**Figs. 2.a**). The distance between the testing machine's jaws was 700 mm for the specimens with concrete that were subjected to monotonic loading. As seen in **Fig. 2b**, the concrete specimens were made utilizing a vertical plastic frame. The frame's vertical posture was maintained by simple props. The with concrete specimens were constructed using splices that were 700 mm long, with 600 mm of that length implanted in a concrete cylinder. The external diameter of the concrete cylinder was Dc = 121 mm for the splices made of d_b = 16 mm rebars and Dc = 151 mm for the splices made of d_b = 20 mm rebars (**Table 1**). The concrete cover has a significant impact on the bond characteristics and crack pattern. The concrete cover was 52 mm at the rebar, 49 mm at the coupler (TC) and 47 mm at the coupler (OTC) for members incorporating 16 mm bars, and 65 mm at the rebar, 60 mm at the coupler (TC) and 59 mm at the coupler (OTC) f (**Fig.1**). The concrete cover was chosen to take into consideration the experimental restrictions, minimize the occurrence of splitting failure along the implanted bars, and maintain the same cover-to-rebar ratio (c/d) for all with concrete specimens. For both rebar diameters, c/d = 3.3 is above the limit value at which splitting is anticipated to happen when there is no or minimal transverse confinement (c/d = 1) [25,33] and above the limit at which cover splitting can be entirely disregarded (c/d = 3) [25,34]. The compressive strength of three 150 × 150 × 150 mm^3 cubic samples of concrete was evaluated. They had been tested under compressive force after being submerged in water for 28 days. **Table 2** provides the compressive strength of the cubic samples and the equivalent compressive strength of the cylinder samples. It should be noted that the equivalent compressive strength of a cylinder is determined in accordance with BS 1881: Part 120:1983 and is based on the assumption that a cylinder's strength is 0.8 times that of a cube's strength [35].



(a)

(b)

Fig. 2. Construction process of specimens OTC (a) OTC, (b) with concrete specimens.

Table 2

Properties of concrete.

Sample	Compressive strength of cubic samples (MPa)	f'c (MPa)	ε_{c0} (%)	ε_{cu} (%)	Weight (Kg)	Mass (kg/m^3)
A	50.42	43.14	0.230	0.386	7.20	2150
B	51.23	44.28	0.225	0.376	7.30	2160
C	50.95	43.86	0.241	0.401	7.25	2140
Average values	50.86	43.34	0.232	0.388	7.25	2150
Standard deviation	0.20	0.16	0.212	0.338	7.30	2.160

3. Instrumentation and Testing Procedures

A static universal testing machine, its hydraulic system, controller, and a test specimen with an extensometer for without concrete specimens and two strain gauges for concrete specimens (one for the coupler and one for the rebar) are shown in **Fig. 3** as the test setup for mechanical bar splices. A sample's maximum length of 1092 mm might be accommodated by the all-purpose testing device. The machine had a 178-mm overall stroke. The machine could produce a force of up to 500 kN in the dynamic state and 600 kN in the static state. Furthermore, the accuracy of the loads and head displacements provided by this universal testing equipment is 1.0 N and 0.0001 mm, respectively. The sampling frequency for machine data was 10 Hz. For all test specimens, a consistent geometry was required to reduce variability in the outcomes. Figure 4 displays the chosen geometry for reference non-spliced bars (per ASTM E8 [36]) and spliced specimens, which were created in accordance with the specifications outlined in [19]. Based on the dimensions of the bar and the length of the mechanical bar splice (L_s), the total specimen length (L) was calculated. The coupler length plus α times the bar diameter (α_{db}) from each side of the coupler ends is known as the coupler region length (L_{cr}). In the present study, alpha was more than twice the bar diameter [19]. The bar length from outside the coupler region to the grip was at least 16 times the bar diameter to avoid any localized failure. For regular bar testing, ASTM E8 and ISO ISO/DIS 15835 [19,36] require at least 5 d_b grip-to-grip length. Extensometers were used to measure the strains of non-spliced and spliced specimens, respectively. The bar extensometer had 100-mm stroke and could measure strains until the fracture of the bar. The with concrete tests were put through a low cycle loading test, in which the sample was originally put through 20 cycles ranging from 90% of its yield strength in tension to 50% of its yield strength in compression, as schematically shown in **Fig. 4b**. The process entails raising the test specimen's tension once the cycling is finished until failure.[19]

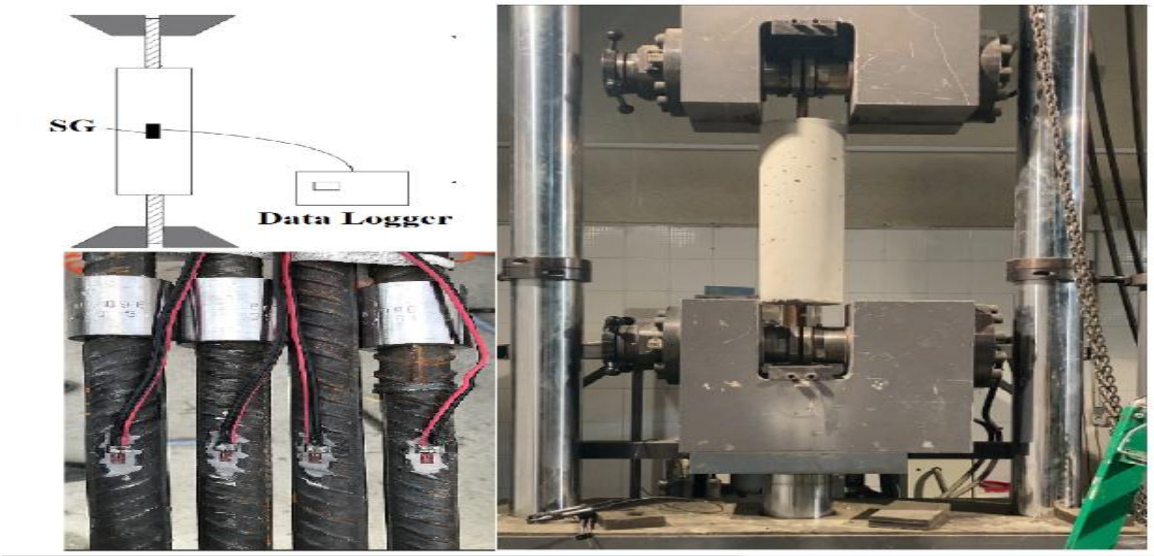
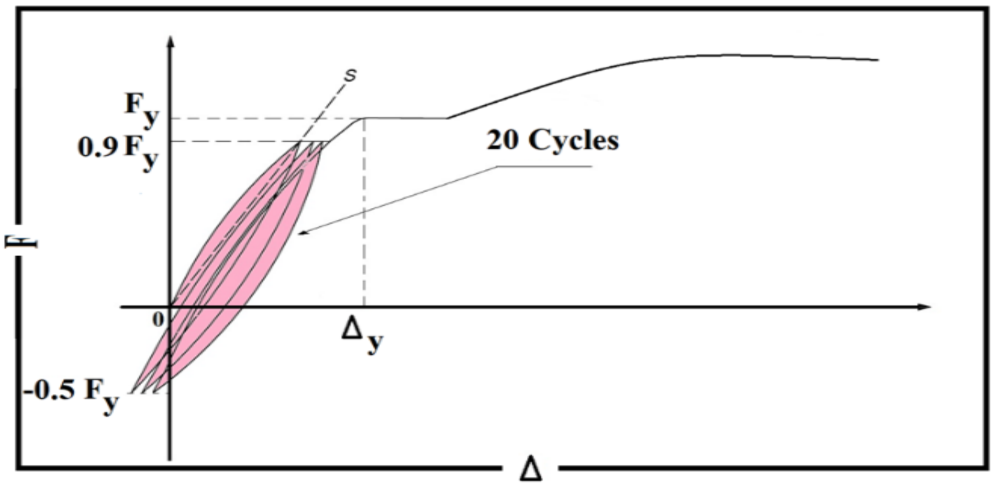


Fig 3. Testing configuration for without concrete specimens and with concrete specimens.



(b)

Fig 4. Alternating tension and compression tests for mechanical splices with high stresses [19].

4. Results and Discussion

Mechanical bar splices and non-spliced bars with 20 mm splices were tested utilizing monotonic and cyclic loads (**Fig. 5**). This experimental program includes two distinct types of couplers (TC and OTC). Three spliced specimens were evaluated each product, with at least one non-spliced bar tested as a control sample. **Table 3** summarizes the key findings from the monotonic and cyclic testing on embedded mechanical splices in terms of yield strength F_y and ultimate strength F_u. The table also provides the matching overall yield ε_y and ultimate ε_u mean stresses, which are calculated for qualitative comparisons by dividing the recorded machine displacement by the member clear length, which includes the concrete region and free rebar area. A ductility ratio μ is also supplied, which is calculated from the ultimate-to-yield mean strain ratio $\varepsilon_u/\varepsilon_y$. With concrete members combining non-spliced and spliced 16 mm and 20 mm rebars, as shown in **Fig. 6**, there is a consistent reduction in ε_u with splice type and type of loading. It is also worth mentioning that the uniaxial tests revealed lower ε_u for with concrete members than for without concrete specimens, implying that the with concrete response might be considered a conservative lower bound for splice performance [3,9,14,25]. Bompa [25] developed four performance parameters for comparative analysis to qualitatively investigate the strength, deformation capacity, and size influence of mechanical splices: (a) the ratio of the splice's ultimate tensile strength to the yield strength of the non-spliced rebar, $\sigma_{y,sp}/\sigma_{y,b}$; (b) the ratio of the splice's ultimate tensile strength to the rebar's ultimate tensile strength, $\sigma_{u,sp}/\sigma_{u}b$; (c) the ultimate strain ratio between spliced and non-spliced $\varepsilon_{u,sp}/\varepsilon_{u,b}$, (d) a size factor calculated as the product of the coupler's diameter and length ($d_c \times L_c$) and the length of the coupler region ($L_{cr} = Lc + 4 \times d_b$), where d_b is the original.

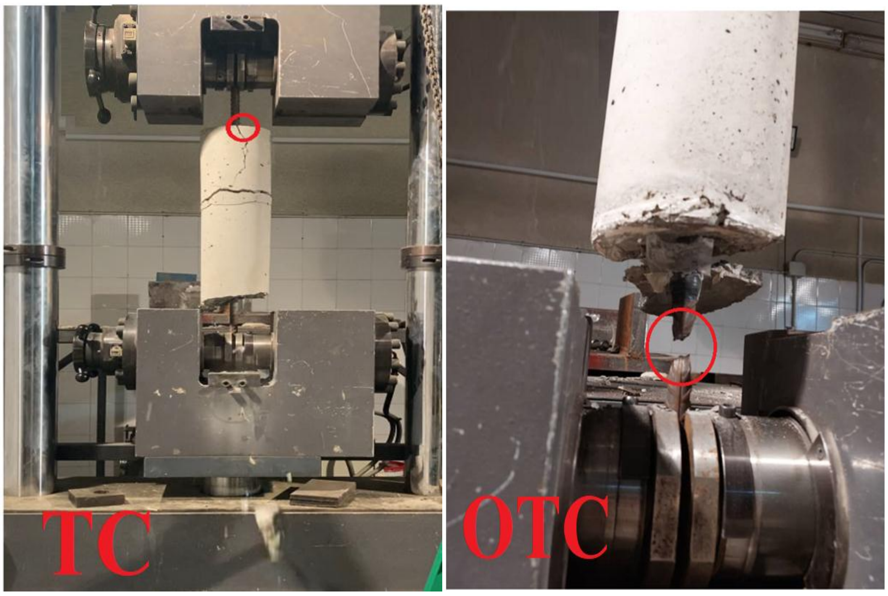


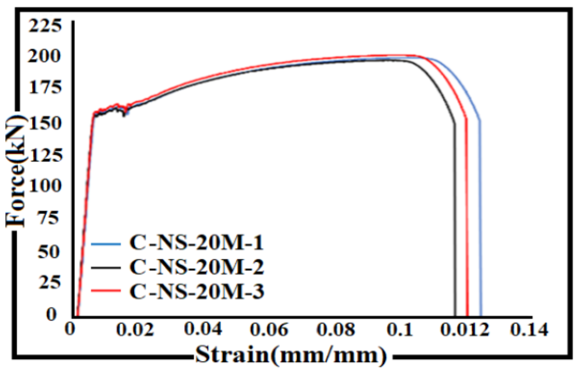
Fig. 5. Failure locations of investigated specimens NS, TC and OTC (16 mm and 20 mm), a) Without concrete specimens, b) With concrete specimens.

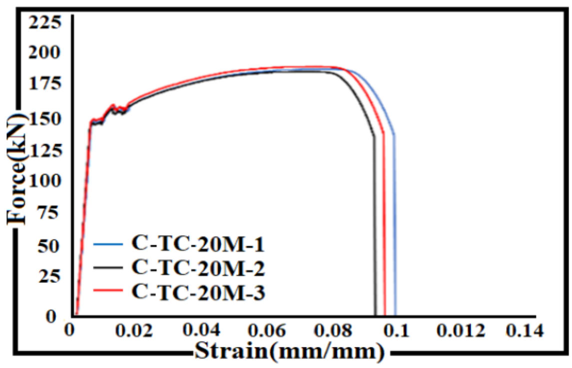
Table 3

Test results of concrete members*.

Specimen	F_y (kN)	F_u (kN)	f_y (MPa)	f_u (MPa)	ε_y (mm/mm)	ε_u (mm/mm)	μ_ε (ε_{usp}/ ε_{ub})	μ (ε_u/ ε_y)	R_u (%)	Ry (%)
C-NS-20M-1	161	199	543	694	0.0047	0.114				
C-NS-20M-2	157	197	517	689	0.0040	0.104				
C-NS-20M-3	168	198	557	698	0.0045	0.110				
Average	162±4.5[h]	198±0.8[h]	539±17[h]	693±3.7[h]	0.0043±0.00029[h]	0.109±0.004[h]	1.00	25.35	-	-
C-TC-20M-1	165	190	522	672	0.0044	0.086				
C-TC-20M-2	160	185	530	653	0.0046	0.080				
C-TC-20M-3	163	188	518	661	0.0043	0.082				
Average	163±2.1[h]	187±2.1[i]	523±5.0[h]	662±7.8[i]	0.0044±0.00012[h]	0.083±0.003[i]	0.76	18.90	122.82	97.03
C-OTC-20M-1	164	197	525	690	0.0038	0.091				
C-OTC-20M-2	167	197	532	697	0.0043	0.086				
C-OTC-20M-3	165	194	528	692	0.0038	0.082				
Average	165±1.2[hi]	195±1.4[h]	528±2.9[h]	693±2.9[h]	0.0040±0.00024[h]	0.086±0.004[i]	1.01	21.50	128.57	98.00
C-NS-20C$_2$-1	165	198	525	689	0.0048	0.112				
C-NS-20C$_2$-2	162	197	517	685	0.0046	0.106				
C-NS-20C$_2$-3	165	199	520	689	0.0049	0.109				
Average	164±1.4[jk]	198±0.8[j]	521±3.3[j]	688±1.9[jl]	0.0048±0.00013[jk]	0.110±0.002[j]	1.00	2.300	-	-
C-TC-20C$_2$-1	162	185	517	650	0.0037	0.084				
C-TC-20C$_2$-2	158	182	515	648	0.0040	0.078				
C-TC-20C$_2$-3	162	185	517	650	0.0039	0.081				
Average	161±1.9[j]	184±1.4[k]	516±0.9[j]	649±1.0[k]	0.0039±0.00013[l]	0.081±0.002[k]	0.73	20.75	124.00	99.04
C-OTC-20C$_2$-1	168	197	530	685	0.0043	0.090				
C-OTC-20C$_2$-2	168	197	530	687	0.0035	0.086				
C-OTC-20C$_2$-3	167	196	529	683	0.0040	0.086				
Average	168±0.5[kl]	197±0.5[j]	530±0.5[k]	685±1.6[j]	0.0039±0.00033[l]	0.088±0.002[l]	1.00	22.60	131.48	101.73

***Different letters in the same column indicate significant differences (P < 0.05).**





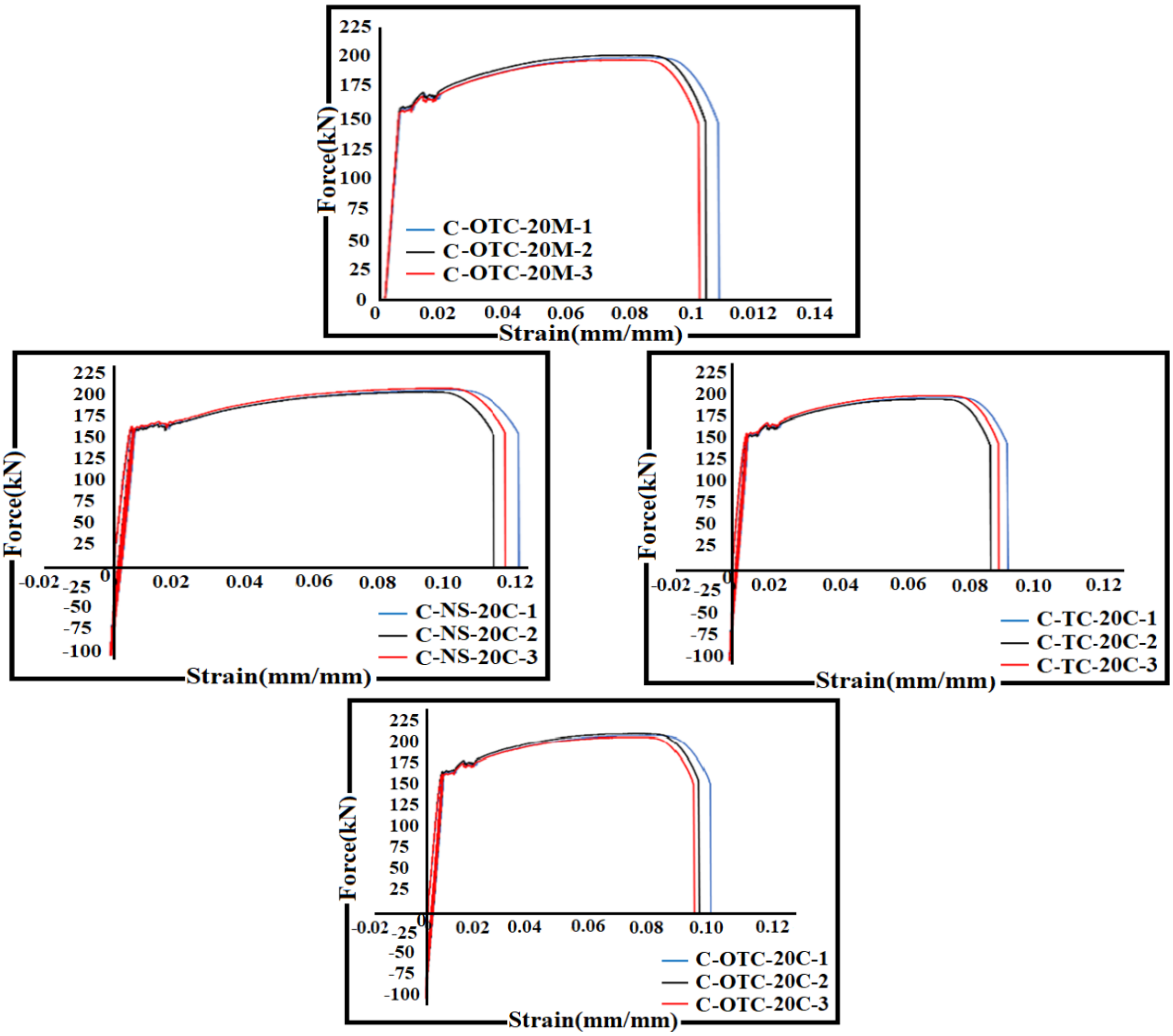


Fig. 6. With concrete test F-ε relationships: monotonic and cyclic specimens NS, TC, OTC, and RFWTC (20 mm).

5.Conclusions

In this study, a novel solution was introduced for threaded splices in seismic regions where flexible structures are present. The proposed approach involves using an enlarged splice area and oversize-threaded couplers. A series of experiments were conducted on more than 18 couplers, including those with oversize threads, subjected to uniaxial tensile and cyclic loading with the presence of concrete. The results indicated that during the elastic cycle test, the oversize-threaded couplers exhibited stress levels similar to those of the non-spliced reference bars, with no significant slippage observed at the threaded points. However, cyclic loading had a negative impact on the behavior of the spliced connection with concrete, leading to a reduction of up to 18% in strain at fracture compared to monotonic specimens. This reduction in strain was attributed to the enlarged cross-section of the rebar near the threaded area, which shifted the weak zone away from the coupler region. The use of oversize threads was found to enhance the performance of the couplers embedded in concrete members. The oversize-threaded couplers, specifically the ones with enlarged threading dimensions, met the performance requirements for structural members subjected to cyclic loading and complied with seismic zone standards, making them suitable for high seismic zones. Additionally, the couplers with standard threading dimensions demonstrated satisfactory performance in terms of strength, energy dissipation, and failure mode, making them suitable for structures subjected to low-to-medium earthquake loads. Energy absorption was identified as a crucial factor in evaluating the behavior of the couplers. To achieve improved energy absorption compared to non-spliced bars, the oversize-threaded couplers required an increase in threading size. The ultimate tensile load capacity of the couplers was found to increase with the enlargement of the threaded area. Among the tested specimens, the oversize-threaded couplers with an extended embedded bar length exhibited the best performance, demonstrating higher ductility ratios than the non-spliced bars and surpassing 125% of the bar yield strength as prescribed by design codes. Overall, the proposed oversize-threaded couplers offer significant advantages in terms of connection efficiency and ease of implementation for mechanical rebar connections in seismic regions.

6-Acknowledgements

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Nomenclature

A_c	**Cross-sectional concrete**	**Fu**	**Ultimate load/peak load**
A_{co}	**Cross-sectional area**	**F_{us}**	**Thread splice sample's load-carrying capacity**
D	**Coupler Diameter**	**F_{ut}**	**Ultimate tensile load of the threaded area in the bar and coupler**
D_1	**Concrete Diameter**	**F_{ut}**	**Tensile load resistance of the concrete**
E_{tc}	**Elastic modulus of the coupler**	**K**	**Stress concentration factor**
F	**Load**	**L**	**Specimen length**
F_c	**Load of the concrete**	**L_{Con}**	**Concrete Length**
F_y	**Yield load**	**L_C**	**Coupler length**
L_T	**Thread ength**	**L_S**	**Splice length**

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