

DESIGN PROBLEMS IN LAP WELDED JOINTS OF REINFORCING STEEL BARS

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Abstract: High compression loads are well sustained by concrete elements, while tensile loads are poorly tolerated. Therefore reinforcing steel bars of various standard sizes and lengths are used for the design of Reinforced Concrete Structures. Due to length limitations of the reinforcing bars, and in order to maintain continuity of the reinforcement, splicing is used so that the desired continuity is accomplished. Lap welded splices of reinforcing steel bars suffer from eccentricity problems and probable failures of the surrounding concrete due to the kinematic behaviour of the end connections. The constantly changing anti-earthquake regulations and seismic design criteria have critically affected the adequacy and reliability of the design and use of such splices. A numerical simulation is undertaken in this paper in order to examine the reliability and behaviour of lap welded steel splices, for loads up to the yield point region of the reinforcing steel.

Keywords: LAP WELDED SPLICES, ECCENTRICITY, SEISMIC DESIGN, REBAR

1. Introduction

In order to satisfy the needs for extension of structural elements in concrete structures, like beams and columns, the most common practice is the method of lap splicing, providing that sufficient steel length is available.

Mechanical connections are cost effective and they are usually made with proprietary splice devices of which the effectiveness and application is accomplished on a per piece basis, providing that they satisfy the code requirements [1-4]. In Greece this procedure is governed by the ELOT 1421-3, KTX 2008 and ELOT 971 codes [5-7].

Lately in newly erected reinforced concrete structures constructional faults are portrayed in the reinforcement of the structural elements. The constructional errors create divergence from the relative provisions of the Technology of Steels code (KTX 2008) and uncertainty in their behavior after an intense seismic event. A case of problematic formation and tying of joints, mainly in the reinforcement in the vertical main direction and foundation members has a negative influences on the mechanical attributes of the construction elements due to appearance of deviation phenomena (lateral displacement of the welded ends). The problem was intensified progressively and particularly after the increased use of welded meshes combined with insufficient technical supervision.

Indicative of the situation is Figure 1 from newly erected structures where it is often observed reduced ties in the vertical direction of the reinforcement of columns and consequently the existence of bars with free length of 200 to 1000 mm.

The popular lap welded joints of reinforcing bars, shown in Figure 2, according to specifications [ELOT]971, [KTCH] 2008, [ELOT]1421 [5-7], present functional problems related to the following:

1) different behavior of the connection in tension and compression, with the development of additional intensity due to eccentric axial loading [8], [10] and

2) caused displacement of the end connections in the welded region [8], [10].

Constructional faults of the vertical bar connections with the fasteners, create reduction of the yield strength, and elimination of the corresponding safety factor against seismic actions.

In the present paper as also in work [9], the tensile mechanical behavior of lap welded joints is examined:

- with the aid of numerical analysis
- by application of elastic analysis up to the appearance of cracks in the exterior fiber of the reinforcing bars, and
- by application of bilinear behavior of the tension and examining the progressive and complete plasticity of bar cross-section.

The factors that are seriously considered in the analysis of the lap welded joints are: The bar diameters ($d= 8, 10, 12, 14, 16, 18,$ and 20 mm), the length of the weld ($4d$ and $5d$), the distance “a” between the ends of the welded parts and the free length of bars “l” for $l=300, 400, 500, 600, 700, 800, 900,$ and 1000 mm.



Fig. 1 Poor practice of ties in vertical columns

In the present article the development of tensile axial loads are calculated in the region of connection and the corresponding displacement of the ends of the rebar.

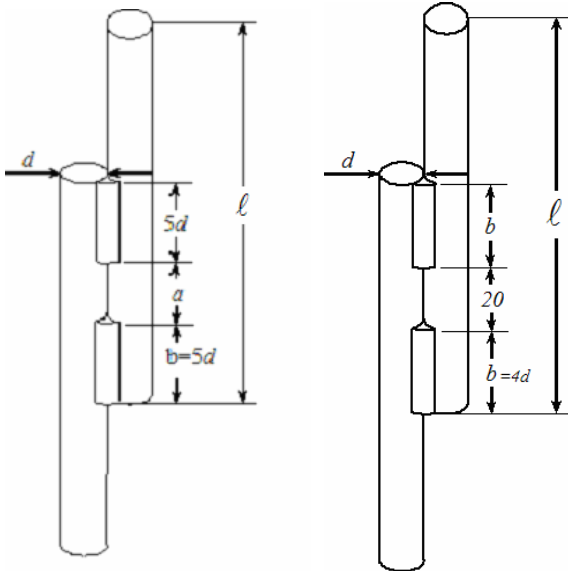


Fig. 2 Schematic of welded lap joint of reinforcing steel specimens

2. Numerical Simulation

In order to study the tensile mechanical behavior of the lap welded joints, the influence of the various geometric characteristics of the steel bars and of the welds, along with the appearing sideways movements of the ends of the bars, were examined through considerable linear and non-linear analyses.

For the geometric mesh discretization of the welded bars, assuming smooth outer bar surface, the SOLID45 element of the ANSYS finite element analysis program (FEA) was used. This 8-nodes element with 3-degrees of freedom at each node is shown in Fig. 3, while in Fig. 4 the 3-dimensional beam element LINK8 is presented, which was used to discretize the stirrups.

A typical finite element model of the lap welded rebar is presented in Fig. 5. The model sizes, concerning the number of nodes and elements for each case depend on the examined for each case geometry. Thus the number of nodes ranged between 14000-33000 and the corresponding elements between 12500-30000.

The bar and weld material were assumed to be steel with modulus of elasticity $E = 210$ GPa and Poisson ratio $\nu = 0.3$. The boundary conditions applied to the model concern the complete restraint of all the degrees of freedom of the nodes that are found in the lower end of the bottom bar.

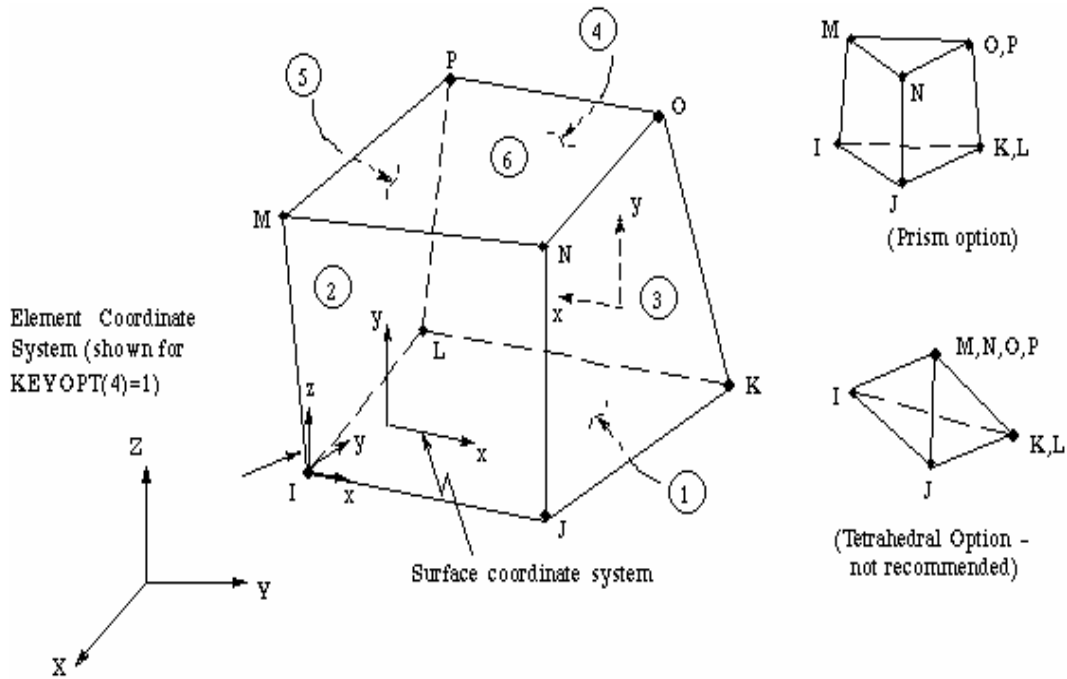


Fig. 3 SOLID45, Finite Element types

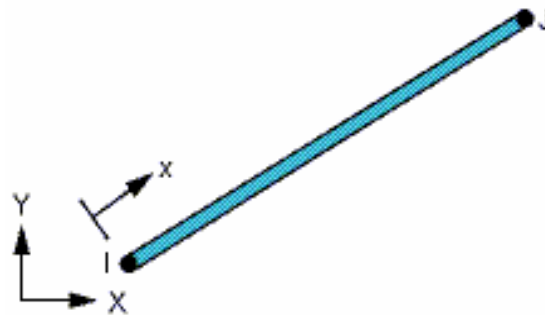


Fig. 4 LINK8 Finite Element types

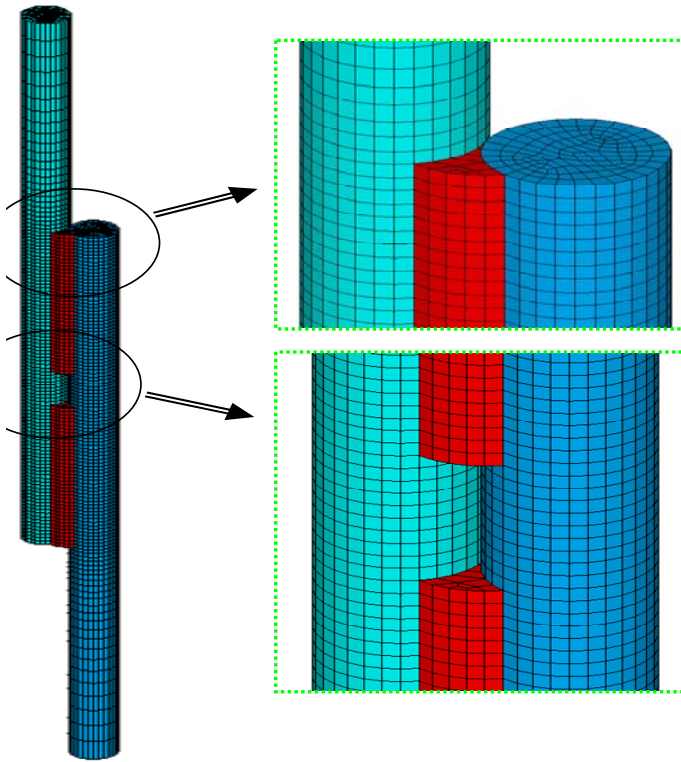


Fig. 5 Lap welded steel reinforcing bars finite element model

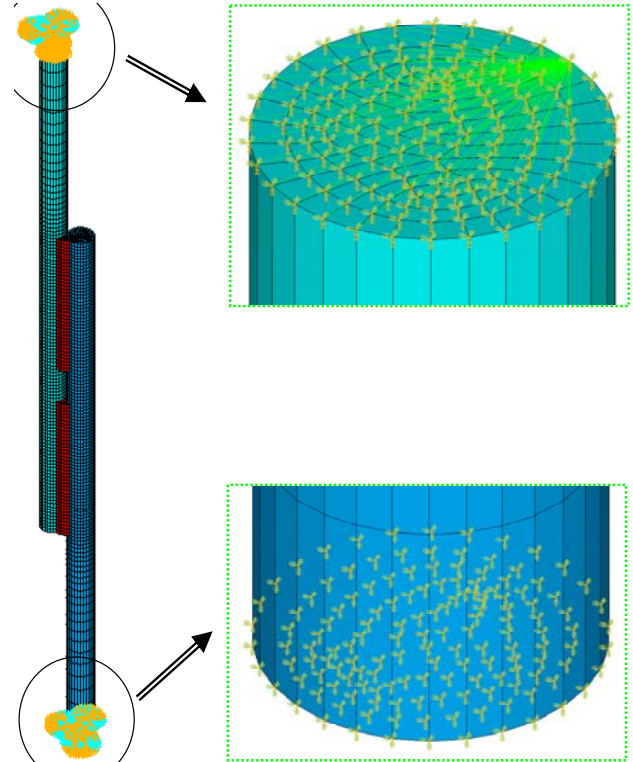


Fig. 6 Boundary conditions at the ends

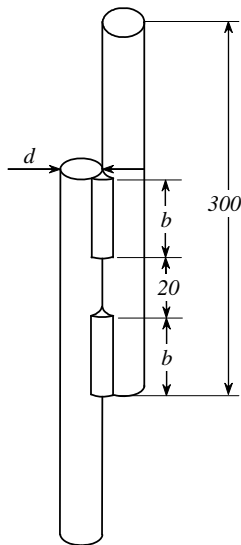


Fig. 7 Geometrical characteristics of the weld

On the nodes of the upper end of the top bar, restrictions were applied on all degrees of freedom except of the vertical bar motion. At the same time on these nodes the same displacement was assigned also in the vertical direction. Figure 6 shows the boundary conditions applied on the finite element model.

3. Results

In the case of normal tension of the lap welded steel joints, the geometry is altered as it is expected, resulting in the dislocation of the edges of the bars. This dislocation is causing initially spot damage of the concrete which will evolve as a local explosion of the overlapped surrounding concrete.

Analysis No 4

Analyses 1-3 were presented in a previous paper [9].

During the group analysis based on the elastic behavior of the rebar and until the yield point value appears on the outer fiber cross-section, the effect of weld length on the calculated displacement of welding rods in tension at the yield point. For the analysis, as the length of rod $l = 300\text{mm}$ was chosen as shown in Figure 7. On the rebar tensile stress of 500MPa was imposed and the analysis was performed by assuming linear elastic behavior of steel.

Table 1 shows the variables used for the geometry of No 1 analyses.

Table 1 Geometric variables for analyses No. 4

Variables	Values (mm)
b	4d , 5d
d	8, 10, 12, 14, 16, 20
a	20, 30, 40, 50, 60, 80, 100, 150, 200

In Figures 8 and 9 and Table 2 the calculated maximum lateral displacements of the ends of the lap welded bars are presented as a function of the variables of Table 1. An increase of the weld length from $4d$ [5] to $5d$ [6] it only reduces the displacement of the lap welded ends by a small amount.

ANALYSIS No. 5 (Non linear)

The non linear behaviour of the lap welded bars according to the non linear behaviour of the material as shown in Fig. 10. An incrementally increasing stepwise 10MPa load was applied on the welded bars. For each loading step, yielding failure of the material was examined. The audit was selecting and displaying only the elements of finite element model, whose tensile strength was less than the yield strength of the material (500MPa). The externally applied tensile strength for which a discontinuity appeared for the first time in the model, it was considered to be as the point of complete yield failure of the welded connection. Figure 10 shows the above procedure. Figure 10 (a) shows the elements of the model with tensile load a step lower than the threshold limit before the yield point of the material.

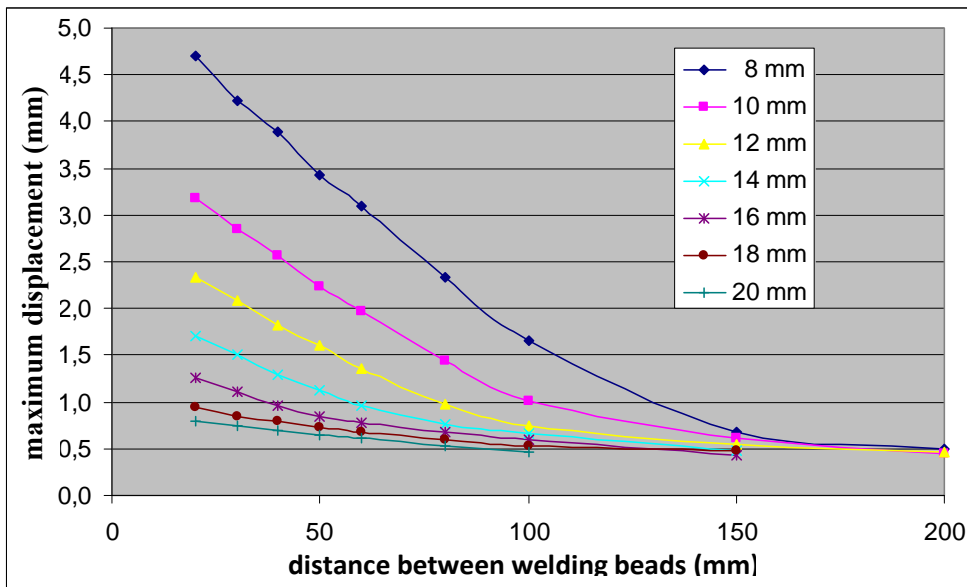


Fig. 8 Lateral displacements of the lap welded bars as a function of the distance between welds for different diameter values d and weld length $4d$.

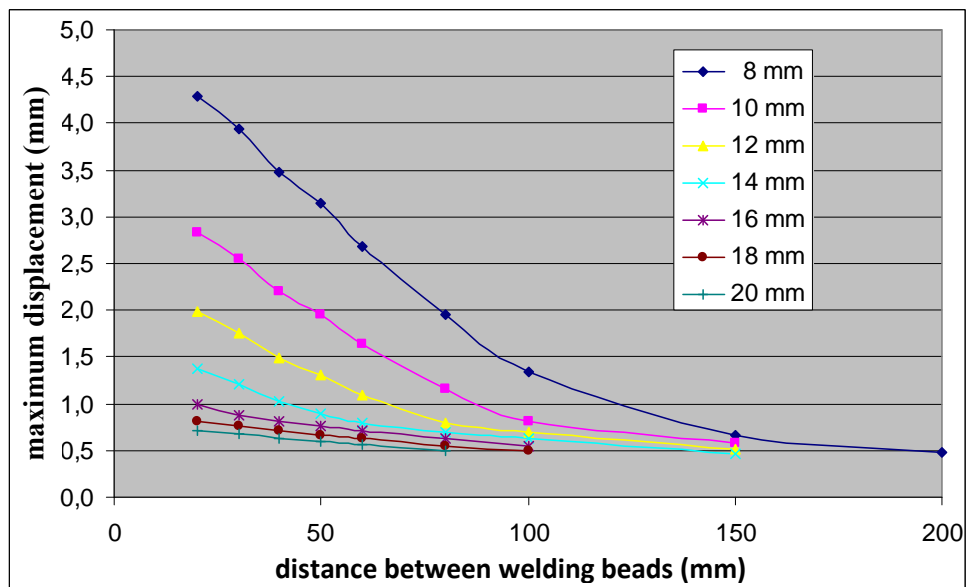


Fig. 9 Lateral displacements of the lap welded bars as a function of the distance between welds for different diameter values d and weld length $5d$.

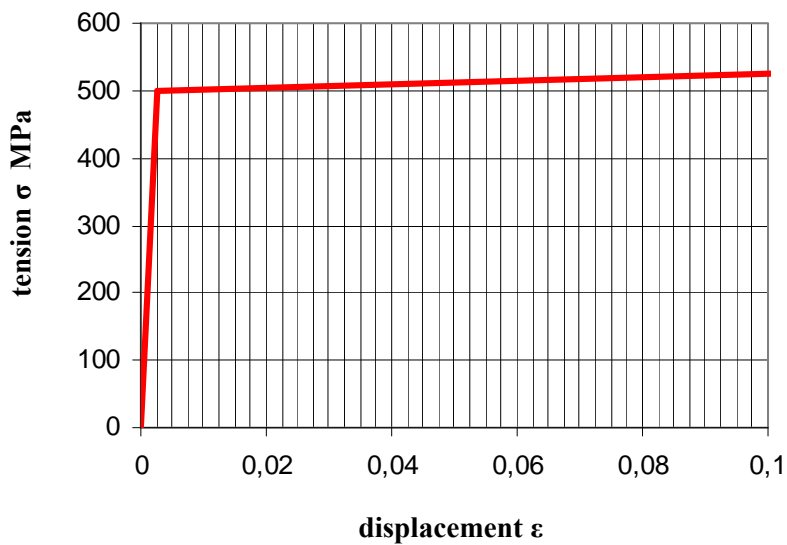


Fig. 10 Mechanical behaviour of steel B500c

Table 2 Maximum displacement of the lap welded joints, analysis

Weld length	Bar diameter (mm)	Bar length (mm)							
		300	400	500	600	700	800	900	1000
4d	8	4,710	4,230	3,885	3,427	3,092	2,333	1,658	0,677
	10	3,186	2,843	2,567	2,227	1,972	1,444	1,010	0,606
	12	2,335	2,094	1,820	1,601	1,360	0,982	0,749	0,546
	14	1,706	1,510	1,298	1,130	0,962	0,761	0,665	0,487
	16	1,263	1,108	0,956	0,844	0,774	0,674	0,591	0,424
	18	0,949	0,851	0,788	0,737	0,684	0,598	0,526	0,479
	20	0,802	0,749	0,695	0,652	0,606	0,532	0,469	
5d	8	4,296	3,945	3,485	3,138	2,685	1,957	1,345	0,655
	10	2,833	2,550	2,209	1,950	1,647	1,167	0,816	0,585
	12	1,981	1,753	1,497	1,300	1,088	0,796	0,700	0,521
	14	1,382	1,209	1,029	0,899	0,801	0,703	0,621	0,456
	16	0,992	0,876	0,805	0,757	0,706	0,623	0,552	
	18	0,809	0,760	0,709	0,668	0,625	0,554	0,491	
	20	0,712	0,671	0,628	0,593	0,556	0,492		

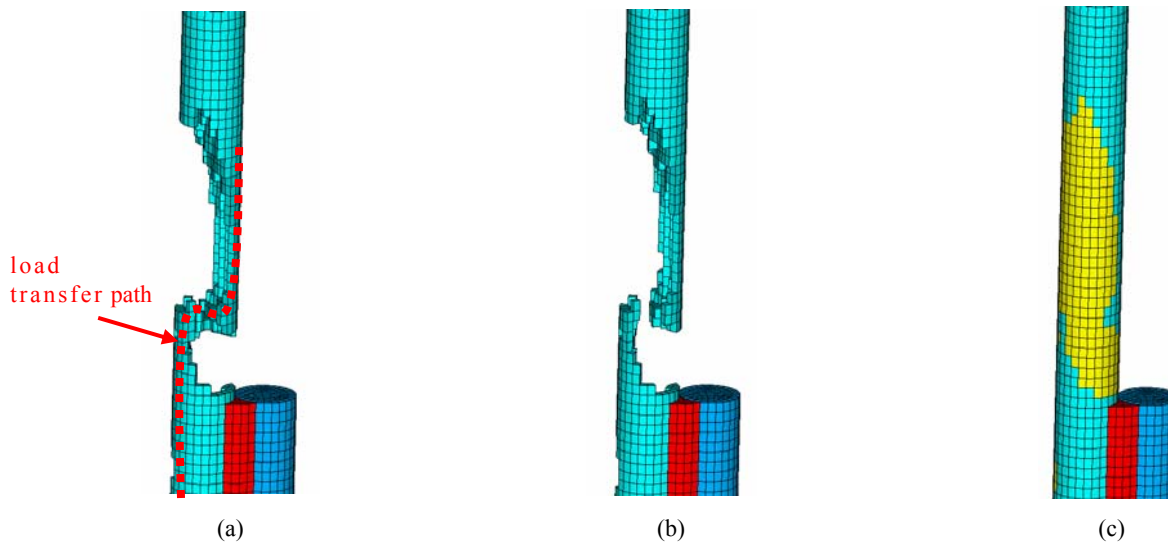


Fig. 10 Tensile failure of lap welded joints

It is observed that while a large number of finite elements has tensile load σ_v over the yield point of the material (elements not shown in this figure), the welded connection remains capable of carrying the applied external load. Unlikely in Figure 10 (b) after complete yielding failure of the connection a discontinuity appears in the model. Finally in Figure 10 (c) marked in yellow, the elements with tensile load above 500 MPa, are shown.

Table 3 presents the results of the nonlinear analysis with the maximum allowable external load until the appearance of full yield for different combinations of geometric features like bar length, distance between welds, and bar diameter.

It is observed that the eccentricity of the lap welded joints precludes the use of the mechanical characteristics of the material B500c with yield point of 500 MPa.

ANALYSIS No.6 (Nonlinear connections)

Non linear connections of lap welded joints were also made, connected with connectors of the same type steel B500c. The geometry of the connections analyzed, is shown in Figure 11.

In order to find the load of complete yield the methodology described in analysis No5 was applied. In Fig. 12 (a) marked in yellow the points of equivalent tensile load greater than 500 MPa, are shown while in Figure 12 (b) these elements are separated in the display of the model, revealing the failure. As in these analyses the increase in load was stepwise of 1 MPa, the total failure trends were calculated with the same accuracy.

The cases examined are shown in Table 4. The same table shows also the results of analysis that concern the tensile load of complete yield failure of the cross section of the bars.

Table 4 shows a great reduction of the deflection of the rod tips when there is retention of the main reinforcement with stirrups.

ANALYSIS No. 7 (Nonlinear analysis with connectors and steel corrosion)

In order to calculate the effect of corrosion on the strength of welded steel bars, the analyses No. 5 were repeated, considering as yield point of the material of one of the two bars equal to $R_p = 470$ MPa. Table 5 presents the failure loads (and the percent variation of the strength) calculated in both corroded and non corroded material.

Table 3 Maximum externally applied load until appearance of complete failure of the joint (analysis 5).

Bar length l (mm)	Weld distance a (mm)	Bar diameter d (mm)	Externally applied load (MPa)
200	20	8	450
200	20	12	460
200	20	16	480
200	30	8	450
200	30	16	500
200	60	8	460
200	60	12	480
300	20	8	440
300	20	16	460
300	30	8	470
300	30	16	460
300	60	12	480
300	60	16	470

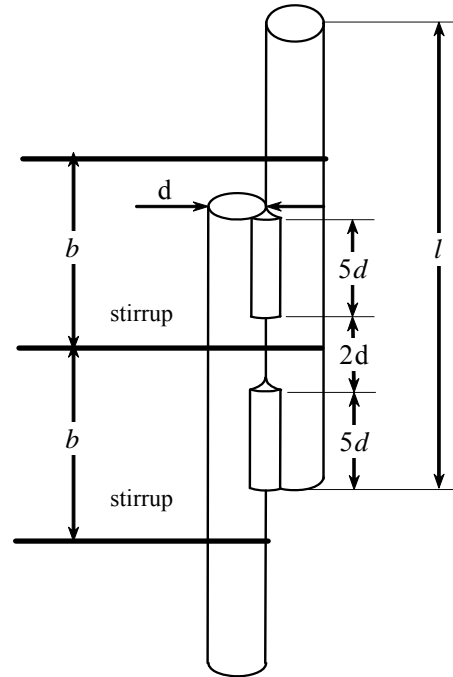


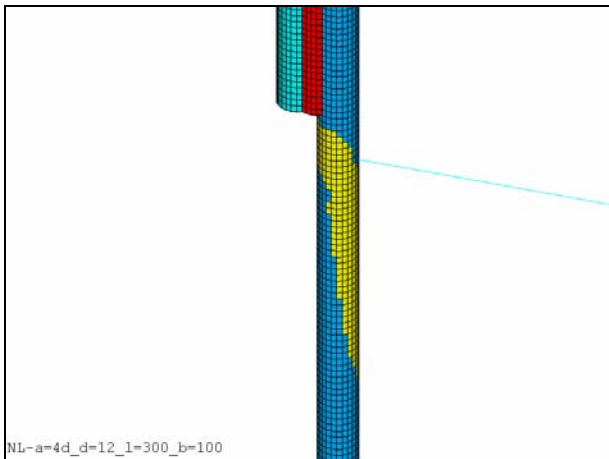
Fig. 11 Schematic of welded lap joint of reinforcing steel specimens with stirrups

Table 4. Maximum external load where complete yield failure of the welded junction appears.

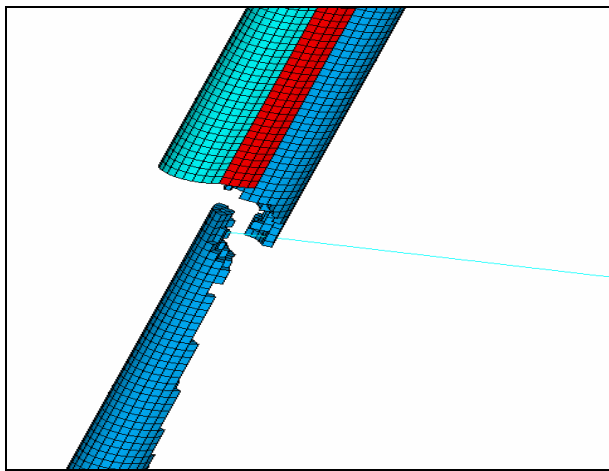
Bar length (mm)	Weld bead length (mm)	Bar diameter (mm)	Distance between Stirrups (mm)	Complete failure (MPa)	Failure prior to yielding (mm)
l	a	d	b		
200	48	12	50	490	0,225
200	48	12	100	482	0,49
300	48	12	50	480	0,171
300	48	12	100	469	0,258

Table 5 Yield point of steel bars for the indicated exterior loading (No. 7 analyses)

Bar length l (mm)	Welding bead distance a (mm)	Bar diameter d (mm)	Exterior failure load (MPa)		% reduction in strength
			Non corroded (Rp= 500MPa)	Corroded (Rp= 470MPa)	
200	20	8	450	430	4.44%
200	20	12	460	440	4.35%
200	20	16	480	470	2.08%
200	30	8	450	430	4.44%
200	30	16	500	500	0.00%
200	60	8	460	450	2.17%
200	60	12	480	470	2.08%
300	20	16	460	440	4.35%
300	30	16	460	450	2.17%
300	60	12	480	450	6.25%
300	60	16	470	450	4.26%



(a)



(b)

Fig 12 Points of failure of the welded bars

4. Conclusions

Lap welded splices of steel rebar are susceptible to eccentricity problems and probable failures of the surrounding concrete due to the kinematic behaviour of the end connections. Questions are raised for their acceptance after workability problems generate significant displacement of the ends and their potential association of the guaranteed nominal mechanical strength of steel (B500c) with yield point of $R_p = 500\text{MPa}$. After the segments long before the external imposition of good R_p load at the ends of the bars, the area of welded connection has already exceeded the yield stress R_p .

A reevaluation of the existing design codes, treating complex tensile or compressive behaviour of welded splices, is mandatory.

Further investigation is required on the welding methods in order to promote and secure the safety of reinforced concrete structures and especially during expansion and addition of new elements.

The regulatory directive to restore continuity in reinforced steel bars with welded fitting quote when steel reinforcement bars make a significant degradation of mechanical components of reinforced concrete.

After that, it would be appropriate, re-discussing the issue with a key to review use similar ways to link the construction of reinforced concrete.

5. References

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