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# GERMAN POSITION ON THE UPDATE OF US ARMY TECHNICAL MANUAL TM 5-1300/NAVFAC P-397/AFR 88-22
(NOW: UFC 3-340-02)

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## Abstract:

The US Army Technical Manual 5-1300 / NAVFAC P-397 / AFR 88-22 is the world's leading guideline for the design of structures to resist the effects of accidental explosions. As an unlimited distribution document approved for public release, TM 5-1300 provides both government and private sector engineers with an invaluable source of blast effects and loading data and with step-by-step procedures for blast analysis and design. In the past this manual has been an outstanding example for guidelines in several NATO countries, including Germany.

In 2003, the US Department of Defense Explosives Safety Board (DDESB) established a Technical Working Group (TWG) to revise the US Army Technical Manual 5-1300. As a result of the TWG's work an update of TM 5-1300 has been presented in 2008.

This paper shows the German scientific position which offers an alternative point of view in special aspects of TM 5-1300. It is focused on chapter 4, “Reinforced Concrete Design”, special emphasis will be placed on RC-elements with single leg stirrups and tolerable rotations on behalf of European reinforcing steel. Different approaches to detailing are made and should be discussed.

## 1. INTRODUCTION

The joint national US Technical Manual TM 5-1300 (NAVFAC P-397 / AFR 88-22) governs the design, construction and production of structural elements aimed to resist the effects of accidental explosions. Released in 1990 as an unlimited distribution document, this Technical Manual has long since become available on the Internet with no obligations to be complied with. As its contents covers a wide range of aspects and the design specifications included have been investigated carefully and verified in complex tests, it has certainly been the most frequently used regulation for reinforced concrete engineering, steel engineering and masonry structures in the context of protective shelter construction. TM 5-1300 provides both government and private sector engineers with an invaluable source of blast effects and loading data and with step-by-step procedures for blast analysis and design. In the past this manual has been an outstanding example for guidelines in several NATO countries, among Germany is one of them.

As early as in 2003, experts of the US armed forces started to revise the contents of the manual. In 2008, the changes envisaged were published during international events [4]. Titled Unified Facility Criteria (UFC) 3-340-02 [3], the manual was reissued as a generally accessible, joint US military construction regulation on 5 December 2008.

As a purely national US military construction regulation, this technical manual has at all times referred exclusively to US construction regulations, which differ greatly from construction regulations valid in other countries. As a result, for German users the manual could never be more than a construction guide in important fields of application, since reinforced concrete engineering, which is based on German national regulations, relies on other strategies to demonstrate load-bearing capacity. Moreover, in Europe types of structural steels are in use, the material properties and, hence, the material parameters of which clearly deviate from those given in UFC 3-340-02.

Since 1992, the provisions governing design and construction of physical structures have followed the different Euro Codes (EC 01, ff) largely acknowledged throughout Europe. With regard to design procedures and the selection of construction material, these codes as well differ greatly from US construction regulations.

Thus planning for physical structures for the protection against weapons effects has always been accompanied by efforts to align the general recommendations included in TM 5-1300 - (UFC 3-340-02) with the rules of construction valid in Europe. This has resulted in a number of rules, which might be more useful in this context. Other rules are only different – due to the different construction material used. This is to be illustrated in the following on the basis of selected examples.

In this context the own examples mainly refer top reinforced concrete engineering, which is described in TM 5-1300 – UFC 3-340-02, Chapter 4, "Reinforced Concrete Design".

Special emphasis will be placed on RC elements with single-leg stirrups (section 2) and tolerable rotations on behalf of European reinforcing steel (section 3). Different approaches for detailing are shown and should be discussed.

## 2. RC ELEMENTS WITH SINGLE LEG STIRRUPS

### 2.1 Recommendations according to TM 5-1300 (UFC 3-340-02)

According to the TM 5-1300 (UFC 3-340-02) Update, a single-leg stirrup consists of a straight bar with a hook at each end. Minimum bar bend requirements for single-leg stirrups depend as follows on both the design support rotation and the scaled distance of the charge from the element [4]:

1. Type A – Single-leg stirrup with a 90-degree hook on one end and a 135-degree hook on the other end. Type A stirrups may be used only if the scaled distance from the center of the charge to the element is greater than 1.0 ft/lb1/3, the design support rotation is 2-degrees or less, and concrete spalling is prevented in accordance with section 4-55. Placement requirements for Type A stirrups are summarized in Figure 1. For elements designed for blast loading on one face only, the 90-degree leg shall be placed on the blast face. For elements designed for blast loading on either face, the 90-degree leg shall be alternated between each face.

2. Type B – Single-leg stirrup with 135-degree hooks on both ends. Type B stirrups may be used only if the scaled distance from the center of the charge to the element is greater than 1.0 ft/lb$^{1/3}$. Type B stirrups are acceptable for all protection categories and thus may be used for design support rotations up to 12 degrees.

3. Type C – Single-leg stirrup with 180-degree hooks on each end. Type C stirrups may be used for all charge separation distances allowed by this manual. Type C stirrups also are acceptable for all protection categories and thus may be used for design support rotations up to 12 degrees.

Hooks shall conform to the ACI 318 Building Code [4]. At any particular section of an element, the longitudinal flexural reinforcement is placed on the interior of the transverse reinforcement and the stirrups are bent around the transverse reinforcement (Fig. 1) [4].

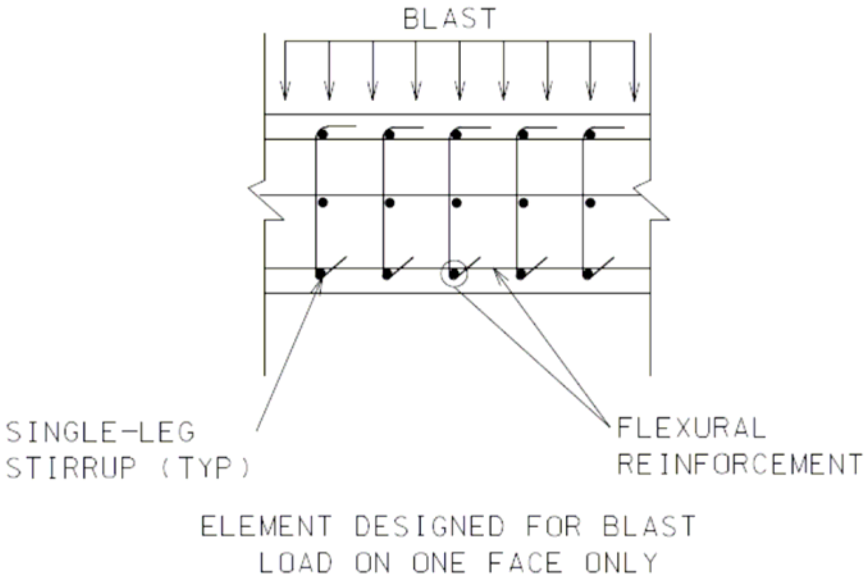


Figure 1: Placement requirements for Type A single-leg stirrups according to TM 5-1300 Update [4]

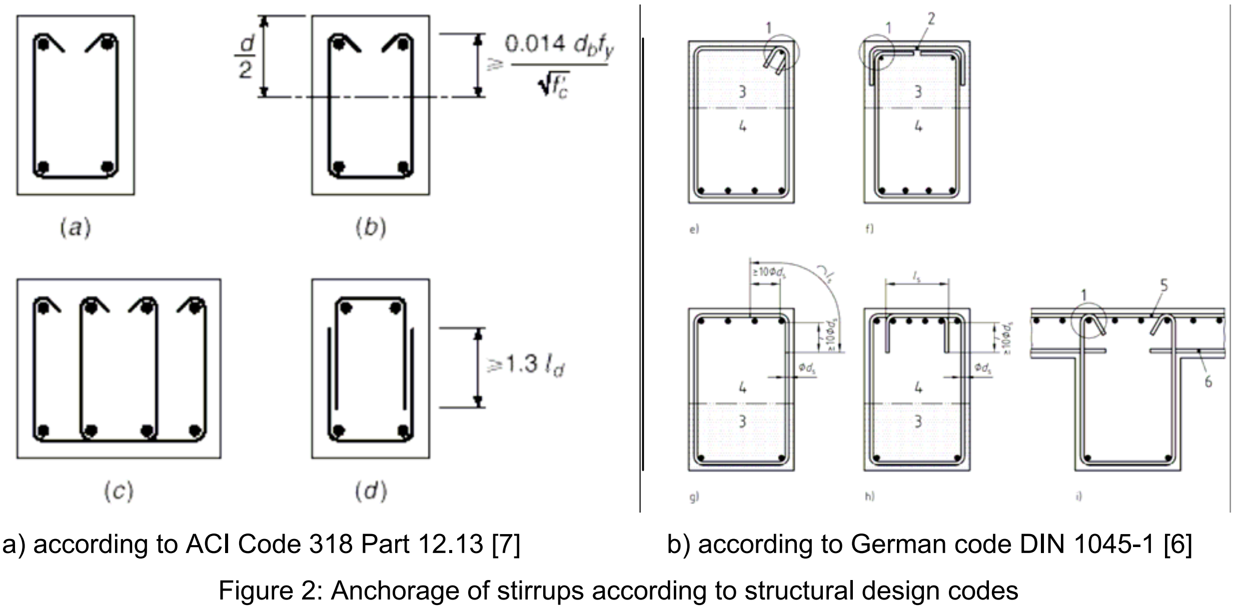
According to [3, 4] Type A, Type B, or Type C single-leg stirrups, as defined above, must be provided if a non-laced element is designed to resist close-in effects. The shear reinforcement must be provided to prevent local punching shear failure. When the explosive charge is located at scaled distances less than 1.0, Type C single-leg stirrups or lacing must be employed. For scaled distances greater than 1.0 but less than 3.0, single-leg stirrups must be provided, while for scaled distances greater than 3.0, shear reinforcement should be used only if required by analysis.

Type A stirrups may be used only if concrete spalling is prevented and the scaled distance is greater than 1.0. If these requirements are satisfied, a slab with Type A stirrups may attain deflections corresponding to support rotations up to 2 degrees under flexural action [4].

A slab with Type B or Type C stirrups may attain deflections corresponding to support rotations of up to 12 degrees. While Type B stirrups may be used only if the scaled distance is greater than 1.0, Type C stirrups are allowed as long as the minimum separation distance requirements of section 2-14.2.1 are satisfied. It should be emphasized that the Section 2-14.2.1 separation distances are the minimum clear distance from the surface of the charge to the surface of the element. The normal scaled distances $R_A$ (center of charge to surface of barrier) corresponding to these minimum clear separation distances are equal to approximately 0.25 ft/lb$^{1/3}$ [4].

## 2.2 Statement and discussion

According to design codes for structural concrete in the US (ACI 318-08 [5]) as well as in Germany (DIN 1045-1 [6]) web reinforcement (laced) has been applied as shown in Figure 2. Both codes require compression zone anchorage with 135-degree hooks, 180-degree hooks or overlapping reinforcement with adequate overlap length.



a) according to ACI Code 318 Part 12.13 [7]    b) according to German code DIN 1045-1 [6]

Figure 2: Anchorage of stirrups according to structural design codes

If these requirements are not fulfilled, in the Ultimate Limit State (ULS) failure may occur especially with accidental loads such as earthquake and blast (figure 3)

Figure 4: Failure according to stirrups with insufficient anchorage after earthquake action [8]

For non-laced RC elements with single-leg stirrups such as slabs the requirements for anchorage of stirrups in the compression zone are similar to multi-leg stirrups in beams. This is stated for instance by LEONHARDT [8] and is also good practice in the design of structural concrete slabs with shear reinforcement. In this context it is irrelevant whether the member's compression zone is intact or damaged by concrete spalling due to weapon effects.

Due to these facts the German party recommends to use **either 135-degree hooks (Type B) or 180-degree hooks (Type C)** for the anchorage of single-leg stirrup reinforcement in the compression zone of slabs with **irrespective of any scaled distance** from the center of the charge to the slab. German codes do not allow 90-degree hooks, because they do not give sufficient anchorage, especially in the case of large deflections and strains. The current revision of the German code for protective structures [9], which is based on TM 5-1300 (UFC 3-340-02), will therefore include these modified recommendations for single-leg stirrup reinforcement in slabs.

The requirements in TM 5-1300 (UFC 3-340-02) for tolerable rotations remain unaffected with respect to the material properties of steel used in Europe (see Section 3).

## 3. TOLERABLE ROTATIONS WITH RESPECT TO EUROPEAN STEEL

### 3.1 Recommendation according to TM 5-1300 (UFC 3-340-02)

As for all short-term loadings such as earthquake loads as well as actions due to detonations, a slab may have good resistance by attaining deflections corresponding to high support rotations. These rotations will be made possible by a stable compression zone in concrete and, above all, by a high ductility of the reinforcing steel used [11]. As stated above, a slab with Type B or Type C stirrups may attain deflections corresponding to support rotations of up to 12 degrees according to TM 5-1300 (UFC 3-340-02).

### 3.2 Statement and discussion

The 12 degrees mentioned in TM 5-1300 (UFC 3-340-02) mean plastic rotations of **$\Theta_{pl}$ = 0,21 rad**. To make these very high rotations possible, two assumptions should be made:

1. the size of the appearing plastic hinges must be large enough and the percentage of reinforcement must be limited to ensure rotation capacity, and
2. highly ductile reinforcing steel must be used.

To quote assumption one, BACHMANN [14] states that the curvature ductility of walls and columns depends on the size of plastic hinge $l_p$ in the theoretical model (see figure 5). Furthermore the ductility depends on the following parameters:

- static system of the structure and the resulting plastic mechanism within the structure,
- geometrical slenderness of structural members, and
- size of the idealized plastic hinge $l_p$.

The assumed size of the plastic hinge is determined by many parameters such as geometrical aspects (shape of cross-section, amount of reinforcement, etc.), material properties (strength, ductility of steel, bond behavior of reinforcement, etc.) and the global static system. Furthermore the plastic hinge is characterized by the interactions between bending and shear within the structural member. The resulting shape of the plastic hinge varies.

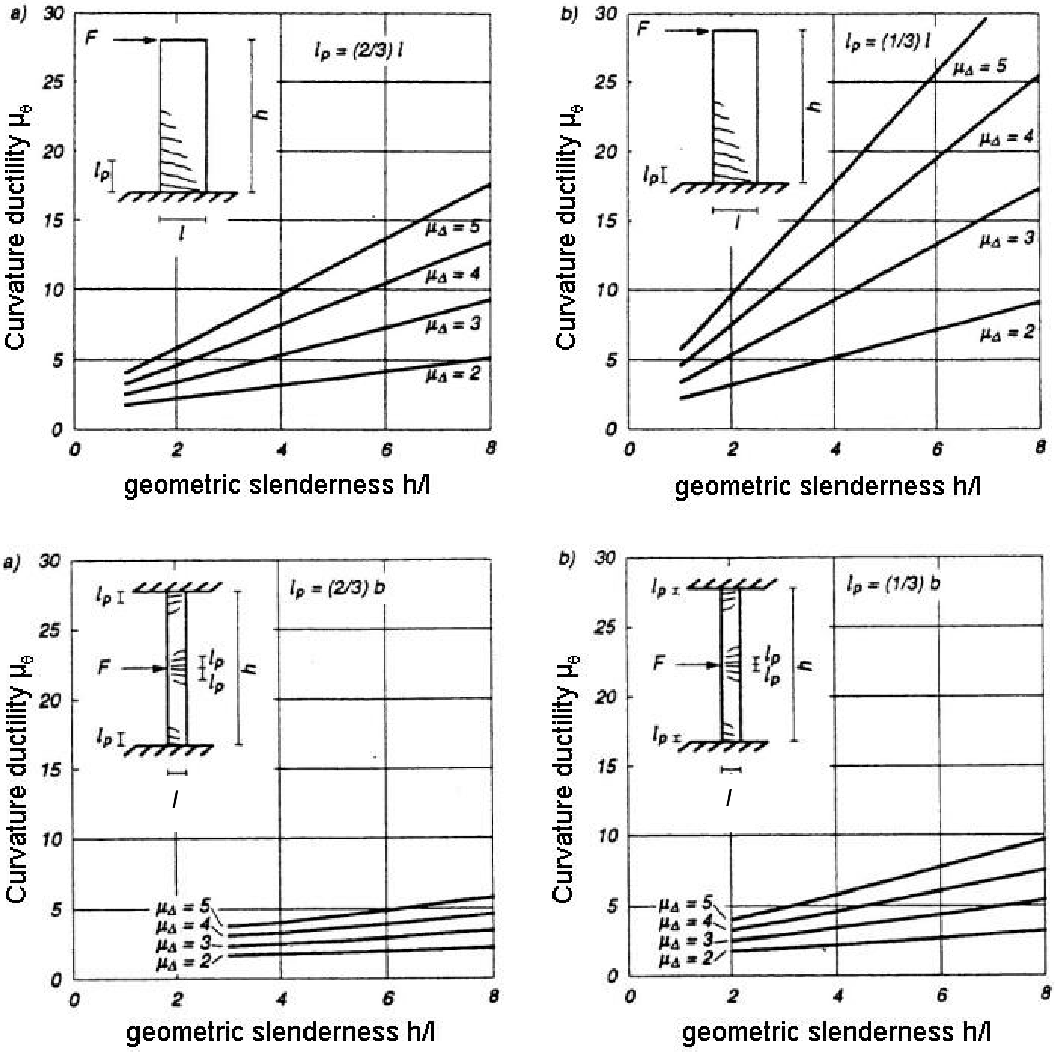


Figure 5: Curvature ductility $\mu_\theta$ of walls and columns vs. geometrical slenderness for various displacement ductilities [14]
with curvature ductility: $\mu_\theta = \theta_{ultimate} / \theta_{yield}$ and displacement ductilitiy: $\mu_\Delta = \Delta_{ultimate} / \Delta_{yield}$

It is therefore not possible to exactly determine the size of the plastic hinge. This is why the ductility of reinforcement steel is one of the main parameters used for establishing proof of rotation capacity in accordance with German code DIN 1045-1 [5] (see figure 6). The procedure used for establishing proof of that rotation capacity is exemplified by ZILCH / ZEHETMAIER [15].

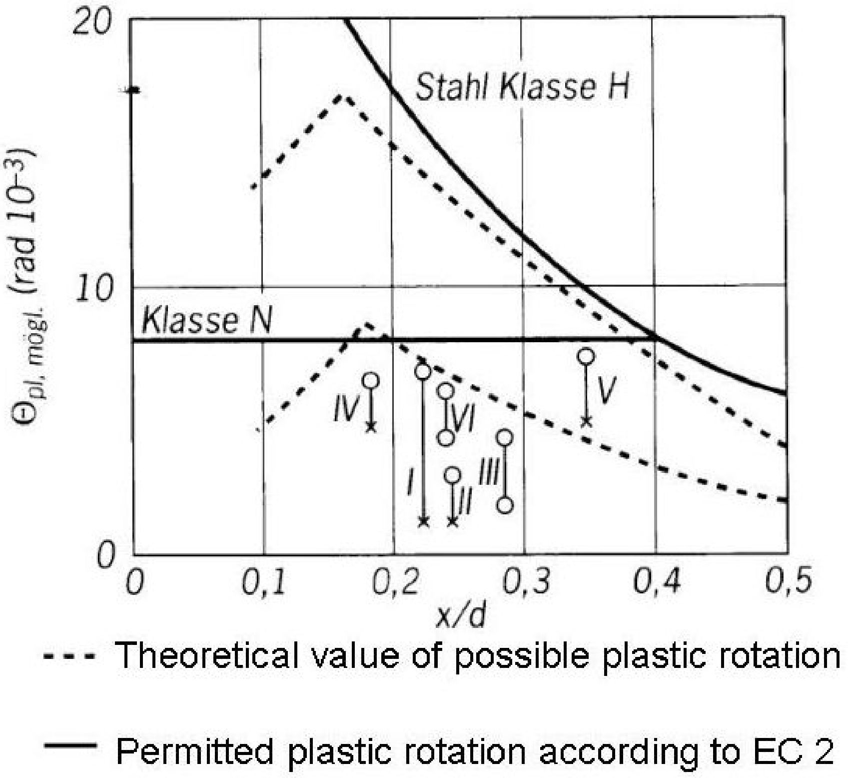


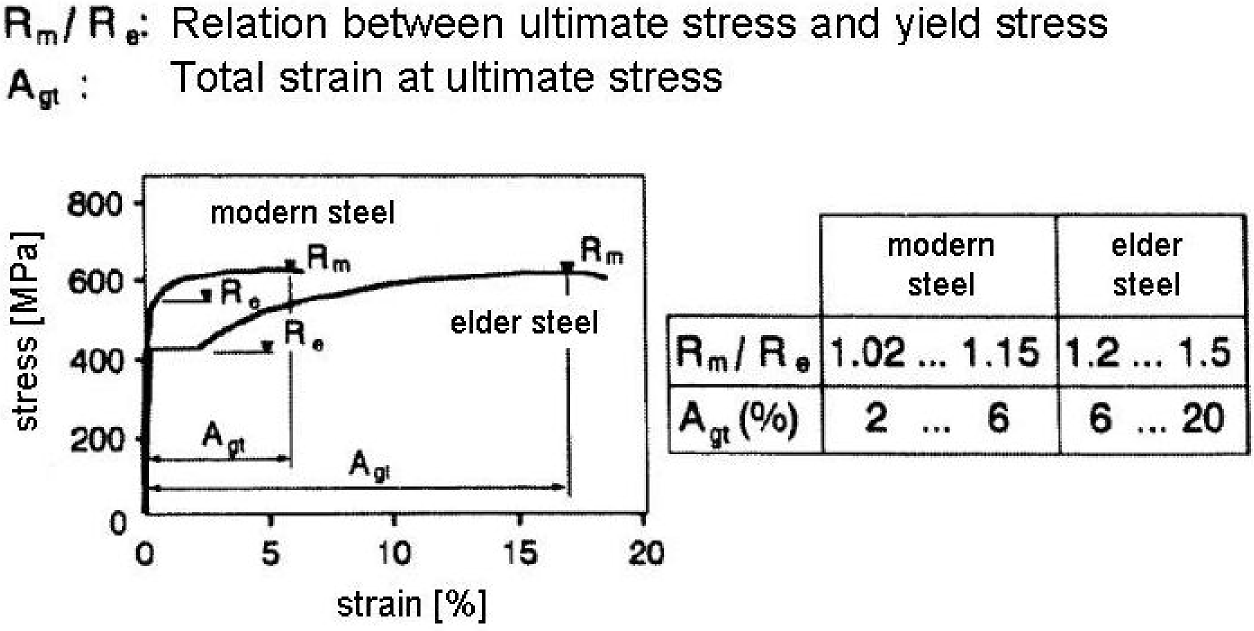
Figure 6: Plastic rotation according to EC 2 and theory with inclining supplement bars [10]

In accordance with German [6] and European codes [12], only reinforcing steel of type BSt 500 with material properties listed in Table 1 below may be used for designing RC structures.

Table 1: Material properties of BSt 500 S class B (high ductility class) [5]

| material property | value |
|---|---|
| | |
| yield stress $f_y$ | 500 MPa |
| tensile strength $f_t$ | 540 MPa |
| ductility ratio $f_t/f_y$ | ≤ 1,08 |
| ultimate strain $\varepsilon_{uk}$ | 50 ‰ |

Unlike older European reinforcing steel such as BSt 220 and American reinforcing steel the ductility ratio $f_t/f_y$ of BSt 500 has a comparatively low value (1.08 compared to up to 1.5 for older European steels in the 1960s). As stated by BACHMANN [13], the ductility ratio $f_t/f_y$ is much more important for ductility assessments than the ultimate strain $\varepsilon_{uk}$. The European reinforcing steel currently used, therefore, shows a dissatisfactory performance in terms of rotation capacity of RC structures and, consequently, in terms of behavior and design for high dynamic loads (see figure 7).



$R_m / R_e$: Relation between ultimate stress and yield stress
$A_{gt}$ : Total strain at ultimate stress

| | modern steel | elder steel |
|---|---|---|
| $R_m / R_e$ | 1.02 ... 1.15 | 1.2 ... 1.5 |
| $A_{gt}$ (%) | 2 ... 6 | 6 ... 20 |

Figure 7: Ductility of modern and older European reinforcing steel [13]

For a better ductility performance in the case of high dynamic loads it is possible to use European reinforcing steel BSt 500 class C instead of BSt 500 class B as mentioned above. BSt 500 class C is also referred to as “earthquake steel” and features a much better ductility behavior. This steel is not mentioned in the German Code DIN 1045-1 [5] and therefore hardly available in Germany. In other European countries such as Norway, however, this steel is regularly used for structural engineering works such as bridges and tunnels [16].

## 4. CONCLUSION

In conclusión of this contribution, the authors recommend to adopt the TM 5-1300 (UFC 3-340-02) Update with additional provisions concerning the construction of RC elements with single-leg stirrups and the reduction of tolerable rotations due to the statements mentioned above.

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