CHANGES TO TECHNICAL MANUAL 5-1300 GOVERNING SHEAR REINFORCING REQUIREMENTS FOR BLAST RESISTANT CONCRETE REINFORCED STRUCTURES

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ABSTRACT

The new version of TM5-1300 has made significant revisions to the design provisions for shear reinforcing in blast resistant concrete structures. These changes allow more flexibility in the use of stirrups in lieu of lacing for limited deflection applications. This paper discusses these new provisions and compares them with previous requirements. A commentary on the significance of these changes is also included.

BACKGROUND OF TM5-1300

The first edition of TM5-1300, "Structures to Resist the Effects of Accidental Explosions (Reference 1), was officially published in June, 1969. The Technical Manual (TM) presented quantitative procedures for design of structures to resist explosive effects. The original version of TM5-1300 focused heavily on reinforced concrete as the principal material of construction. Even with advances in technology and many unique types of materials of construction, reinforced concrete is still the most commonly used material in blast resistant structures. Material and labor costs associated with blast resistant concrete structures are greatly influenced by the type and complexity of shear reinforcement in the element. The old version of TM5-1300 took a very conservative approach to shear reinforcing in blast resistant structures designed for support rotations exceeding 2 degrees. Because of advances in technology and additional testing performed over the last two decades, the new revision of TM5-1300 (Reference 2) contains significant departures from the old TM in the area of shear reinforcement for structures exceeding 2 degrees in support rotation. The new TM also contains subtle changes which greatly enhance an engineer's ability to design a more cost effective structure.

HISTORY OF THE REVISION TO TM5-1300

In 1981 a decision was made to initiate a revision effort to TM5-1300. A significant amount of new test data had been developed since the original publication of the manual. In addition, deficiencies in the existing manual needed to be corrected and new guidance provided for structures other than those constructed of reinforced concrete. Development of the new TM was funded and managed by the U.S. Army Armament Research, Development and Engineering Center (ARDEC). The Project Engineer was Mr. Joe Caltagirone. Revision to the manual was managed by a steering committee with a subcommittee for blast effects technology and one for design applications. Tri-services representation was provided on the various committees. Significant

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contributions were provided by the Naval Civil Engineering Laboratory (NCEL), the U.S. Army Corps of Engineers, Huntsville Division (CEHND), the Ballistic Research Labs (BRL), and the Naval Surface Warfare Center (NSWC). In addition, recognized experts supported the effort through contract efforts. These included Mr. Norvall Dobbs of Ammann and Whitney and Mr. Bill Baker, at that time, from Southwest Research Institute. Because of contracting and funding constraints, serious work on the manual did not begin until late 1982. In June, 1984, a draft version of the manual was released in limited distribution as ARDEC Special Publication ARLCD-SP-84001. Based on significant feedback on the use of this draft version, the expected formal DOD approval of the manual is expected to occur in late 1990.

PURPOSE OF SHEAR REINFORCEMENT

As a general rule, both the new and the old versions of TM5-1300 follow the same basic philosophy for shear reinforcement of blast resistant concrete structures. Both editions of the TM still break down concrete elements into three types of cross sections. Shear reinforcement in these cross sections has varying purposes depending on the design range and type of cross section being considered. The three different types of cross sections are shown in Figure 1 and are discussed in the paragraphs below.

The first cross sections (Type I) are elements which are limited to a maximum support rotation of 2 degrees. Basically, these elements are designed to remain in the elastic/elasto-plastic stress range and are allowed to crack on the tension side, but no crushing or spalling of the concrete is permitted. For these elements, the purpose of shear reinforcement is to simply resist shear stresses in excess of the allowable shear stress value. Single leg stirrups are the most popular form of shear reinforcing in this type cross-section.

The second cross sections (Type II) are elements which are allowed to achieve maximum support rotations ranging from 2 to 8 degrees. These elements are designed to remain intact; however, plastic deformation in the form of crushing of the concrete and permanent deflection is allowed. The purpose of shear reinforcement in these elements is not only to resist excess shear stresses, but also to restrain compression reinforcement. The new TM permits the use of single leg stirrups in this design region, provided support rotations are less than 4 degrees. It also permits the use of stirrups if tension membrane action is present for rotations up to 8 degrees. Lacing can also be used in this region. Lacing is mandatory for scaled distances less than one for all types of cross sections.

The third cross sections (Type III) are elements which are limited to a maximum support rotation of 12 degrees or incipient failure. These elements usually are used as dividing walls. Both complete crushing and spalling of the concrete is permitted in these elements. The purpose of shear reinforcing in this design range is to distribute very high and localized shear loads and to ensure confinement of concrete between the flexure and compression reinforcement. Lacing is the most common method of shear reinforcement in this design range except for walls subject to high intensity blast pressures at a scaled distance greater than 1 that do not attain large deflections. In the latter case, the new TM permits the use of shear reinforcement in the form of stirrups.

COMPARISON OF SHEAR REINFORCEMENT REQUIREMENTS

General:

Shear reinforcement requirements contained in the new version of TM5-1300 differ from the old TM for every type of structural element. The scope of the revision is major for elements with Type II cross sections which are designed for support rotations between 4 and 8 degrees. Revisions are less outstanding for other cross sections, but nevertheless have a very significant impact on the outcome of designs and the cost of the structure. A detailed discussion of each change in the TM involving shear reinforcement requirements for blast resistant structures is provided in the following paragraphs. A commentary on each change is provided in the following section.

Dynamic Increase Factors:

The only changes in dynamic increase factors for shear reinforcement are in the increase factors for direct shear and diagonal tension. The old TM5-1300 recommended that no dynamic increase factor be permitted when determining shear capacities. The new TM allows a 1.10 dynamic increase factor to be applied to the minimum yield strength for direct shear (diagonal bar) and diagonal tension (stirrup/lacing) applications in the "close-in" design range. It should be noted that a dynamic increase factor of 1.0 is still applicable to "far-range" design situation for stirrups. Dynamic increase factors for elements in flexure have also changed. These changes in allowable bending stresses indirectly influence shear reinforcement requirements by increasing ultimate resistance. A comparison of dynamic increase factors concerning shear reinforcement is shown below:

	New Technical Manual		Old Technical Manual
	Far Range	Close Range	
Diagonal Tension	1.00	1.10	1.00
Direct Shear	1.10	1.10	1.00

Static Strength Changes:

The old version of TM5-1300 used 60,000 psi as the minimum static yield strength for ASTM A 615, grade 60 reinforcement bars. The new version of the TM allows a minimum strength of 66,000 psi. This change was made because the minimum ASTM yield strength is exceeded by at least 10 percent by almost all reinforcement bar production mills. Because this value is used to determine the required area of stirrups, lacing, and diagonal bars, it results in less shear reinforcement in all types of cross sections.

Design Range For Stirrups:

In the old version of the TM, it was mandatory that lacing be used in all Types II and III cross sections. This meant that lacing had to be provided in all elements which exceeded 2 degrees in support rotation. The new version of TM5-1300 permits the use of stirrups in elements which have support rotations up to 4 degrees, and in elements which have support rotations up to 8 degrees if tension membrane action is present. Stirrups are only permitted in these cases if the scaled distance is greater than 1. This represents a significant departure from the old TM because it permits the use of stirrups in all types of cross sectional elements. Both versions of the TM still recommend stirrups, when necessary, in Type I cross sections but still retain the option of lacing.

Shear Capacity of Unreinforced Concrete:

The old version of the TM used one formula to calculate the shear stress permitted on an unreinforced element. This formula appeared as follows:

$$v_c = \phi[1.9\ (f'_c)^{1/2} + 2500p] \leq 2.28\ \phi(f'_c)^{1/2}$$ where ϕ is equal to 0.85 for all type cross sections

The new version of the TM contains three formulas for calculating shear in an unreinforced element. The shear capacity of an unreinforced element in flexure is limited to:

$$v_c = [1.9\ (f'_{dc})^{1/2} + 2500p] \leq 3.5\ (f'_{dc})^{1/2}$$

Significant changes between the above two formulas are that the ϕ factor has been dropped from the new TM formula and that the use of the dynamic strength of concrete versus the static strength is now permitted in calculating shear capacity. The latter change has no real bearing on the outcome of the value since the dynamic increase factor for concrete in the diagonal tension range is 1.0. It should also be noted that the 2.28 factor has been changed to 3.5 and is now consistent with the American Concrete Institutes (ACI) Building Code (Reference 3).

The second formula for calculating shear in the new TM is for members subject to axial tension. This condition was not addressed in the old TM. This formula appears as:

$$v_c = 2(1 + N_u/500A_g)(f'_{dc})^{1/2} \geq 0$$ N_u taken as negative

The third formula for calculating shear in the new TM is for members subject to axial compression. This condition was not addressed in the old TM. This formula appears as:

$$v_c = 2(1 + N_u/2000A_g)(f'_{dc})^{1/2}$$ N_u taken as positive

Shear Reinforcement Design Ranges:

The ranges where shear reinforcement is required have been completely revised in the new TM. These revisions were made to account for the design range (e.g. close-in or far-range) and the type of structural action present. Minimum design stresses which require shear reinforcement in the old TM appeared as:

Limits	Stirrups	Lacing
$v_u \leq v_c$	0	v_c
$v_c < v_u \leq 2v_c$	$v_u - v_c$	v_c
$v_u > 2v_c$	$v_u - v_c$	$v_u - v_c$

Minimum design stresses in the new TM appeared as:

Cross Section	Structural Action	$v_u \leq v_c$	$v_c < v_u \leq 1.85v_c$	$v_u > 1.85v_c$
Far Range				
Type I	Flexure	0	$v_u - v_c$	$v_u - v_c$
Type II	Flexure	$0.85v_c$	$0.85v_c$	$v_u - v_c$
Type II & III	Tension Memb.	0	$v_u - v_c$	$v_u - v_c$
Close-in				
Type II & III	Flexure or Tension Membrane	$0.85v_c$	$0.85v_c$	$v_u - v_c$

Shear Reinforcement Area Requirements:

The old TM required that stirrups, when necessary, extend a distance of the depth of concrete beyond the point where theoretically required. It also required that stirrups be provided between the face of the support and a section at a distance "d" from the support. The shear reinforcement in this region must be the same as that required at the critical section.

The new TM requires that shear reinforcement requirements be determined at the critical section of the element and that this amount of reinforcement be uniformly distributed throughout the element.

Equations for calculating the area of shear reinforcement required have also been changed. In the old TM, the formula for calculating the required area of stirrups appeared as:

$$A_v = \frac{(v_u - v_c) b_s s_s}{\phi f_s (\sin\alpha + \cos\alpha)}$$

The equation in the new TM now appears as:

$$A_v = \frac{(v_u - v_c) b_s s_s}{\phi f_{ds}}$$

Of particular importance in the above formulas is that the dynamic strength of the reinforcement steel is now permitted to be used. The $(\sin\alpha + \cos\alpha)$ term has also been deleted; however, this value turns out to be 1.0 in most designs and has a very infrequent effect on the outcome of the shear area value.

The formula for calculating the area of lacing required now appears in the revised TM as:

$$A_v = \frac{(v_u - v_c) b_s s_s}{\phi f_{ds} (\sin\alpha + \cos\alpha)}$$

The only change in this formula is that the use of the dynamic strength of the reinforcing steel is now permitted.

Shear Reinforcement Spacing Requirements:

The old TM required that stirrups be spaced so that every 45 degree line representing a potential crack through half of the member depth be intersected by at least one line of stirrups. It further required that when the ultimate shear stress exceeds $b\phi(f'c)^{1/2}$, every such line be crossed by at least two lines of reinforcement. The new TM requires that stirrups be spaced at half the member depth in Type I cross sections and half the depth minus the cover in Types II and III cross sections. In slabs, the new TM requires that stirrups be placed at each bar intersection as a minimum.

Design For Direct Shear:

After publication of ARDEC Special Publication ARLCD-SP-84001, several major changes were incorporated into the final manuscript which will serve as the final version of the new TM. Among these changes were revisions to almost every paragraph involving direct shear requirements. The discussion below is based on the amended version of the Special Report (i.e. the final version of the new TM).

In the old TM for Type I cross section (support rotation less than 2 degrees), diagonal bars were not required if the actual shear at the support (V_s) was less than the direct shear which could be resisted by the concrete (V_d). However, if the reverse case were true, diagonal bars capable of reacting the full amount of actual support shear (V_s) were required. The amount of direct shear that could be resisted by the concrete was determined by the formula:

$$V_d=0.18f'_cbd.$$

The new TM makes substantial revisions in diagonal bar requirements for Type I cross sections and simply supported slabs with moderate amounts of deflection. The new TM (amended) accounts for the shear capacity of the concrete due to the fact that cracking should not occur in these design regions. The new TM assumes that the concrete resists a shear force equivalent to that given by the formula:

$$V_d=0.18f'_{dc}bd$$

Therefore, for Type I cross sections and simply supported slabs with moderate amounts of deflection at their supports, the amount of direct shear that must be resisted by the diagonal bars is the difference in the actual and the allowable. The required area of diagonal bars is determined in the new TM from the equation:

$$A_d=\frac{(V_s b-V_d)}{f_{ds}\sin}$$ where $V_d=0.18f'_{dc}bd$ for < 2 degrees rotation or simply supported slabs with moderate deflections.

For Types II and III cross sections (support rotations exceeding 2 degrees) the old TM required that diagonals be provided to resist the applied support shear. The area of these diagonals was determined by the formula:

$$A_d = \frac{V_s b}{f_s \sin}$$

The new TM requires that for support rotations in excess of 2 degrees, simply supported slabs with excessive rotations, or for sections in net tension, V_d be taken as zero. This requires that all direct shear be reacted by diagonal bars. Therefore, the new TM equation for calculating diagonal bar areas in Types II and III cross sections, where large deflections or net tension is present is given by the formula:

$$A_d = \frac{(V_s b - V_d)}{f_{ds} \sin} \quad \text{where } V_d = 0 \text{ for the cases stated above.}$$

COMMENTARY

Dynamic Increase Factors and Material Strength Changes:

The change in the new TM which permits the use of 66,000 psi as the minimum static yield strength for reinforcement bars has significant impacts on shear reinforcement design for all types of cross sections. This change, combined with the use of dynamic properties of reinforcement in all of the shear formulas, may allow for significant reduction in the amount of shear reinforcement in some blast resistant elements. This change alone may result in a reduction of 9.1 percent to 17.4 percent depending on the design range (close-in or far-range) and the ultimate resistance value of the element. This change may also reduce construction cost in laced concrete elements because laced elements utilizing large reinforcement bars are very difficult to construct. However, this change may be detrimental in some cases where minimum shear reinforcement is required based on the higher ultimate resistance values.

Design Range for Stirrups Versus Lacing:

This change, as described in the previous section, is one of the most significant departures from the philosophy in the old TM. The use of single leg stirrups, in elements which can attain support rotations up to 4 degrees and in elements which obtain support rotations up to 8 degrees when tension membrane action is present, presents significant material, construction, and labor savings over the use of lacing. It should be noted, however, that the use of single leg stirrups is only permitted when the scaled distance is greater than 1. The engineer should also note that single leg stirrup spacing and the size of the bars may become so congested and large, respectively, for support rotations over 4 degrees that the use of stirrups for constructibility reasons may become prohibitive.

Shear Capacity and Spacing Requirements:

The formula for calculating the shear capacity of concrete now permits the use of the dynamic strength of concrete, however this change has no significant impact on the outcome of the value since the dynamic increase factor for concrete is 1.0 for diagonal tension applications. In most cases, the capacity determined by the formulas in the new TM will yield a larger capacity than the old TM. The spacing requirements for stirrups in the new TM tend to negate the benefits gained by increased shear capacities and material properties, particularly if the engineer is not careful in laying out the spacing of the main flexure reinforcement. The new TM requires that stirrups in Type I cross sections be spaced at "d/2" and for Type II cross sections be spaced at "dc/2". It also requires that shear reinforcement be determined for the critical section in the element and be distributed uniformly throughout the element. For slabs, stirrups are required at each reinforcement bar intersection. A design engineer should keep in mind the spacing requirements for shear reinforcement when designing slabs or any other element which may require shear reinforcement. The spacing of the main flexure reinforcement may be effected by shear steel spacing requirements.

Equations for calculating the shear capacity of sections in net tension and compression were added to the new technical manual. These equations are particularly valuable when calculating the reduced capacities of elements in structures such as containment cells.

Direct Shear Requirements:

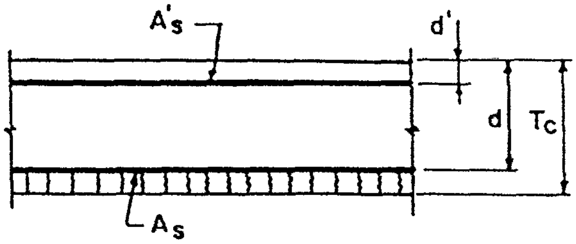
There is no question that the new TM provides a more realistic approach to diagonal bar design. The new TM accounts for the strength of the concrete when sizing diagonal bars for Type I cross sections and simply supported slabs with moderate support rotations. For Types II and III cross sections and sections in net tension, diagonal bars capable of resisting the actual support shear are still required.

REFERENCES

1. "Structures to Resist The Effects Of Accidental Explosions", TM 5-1300 dtd. June 1969.

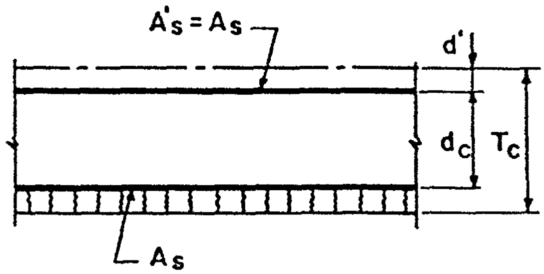
2. "Structures to Resist The Effects Of Accidental Explosions Vol. IV, Reinforced Concrete Design", Special Publication ARLCD-SP-84001, dtd. April 1987.

3. "Building Code Requirements for Reinforced Concrete, ACI 318-83 Rev. 1986", American Concrete Institute, Detroit Michigan.



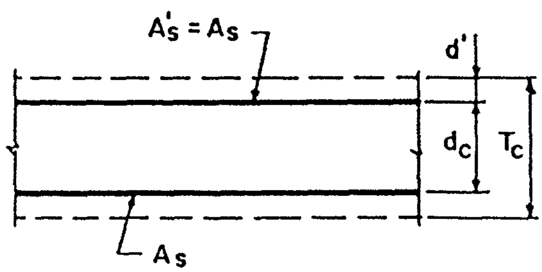
NO CRUSHING OR SPALLING

TYPE I



CRUSHING

TYPE II



SPALLING

TYPE III

LEGEND:

- (cracking pattern) CRACKING
- —·— CRUSHING
- ---- DISENGAGEMENT

CROSS SECTION TYPES

FIGURE 1