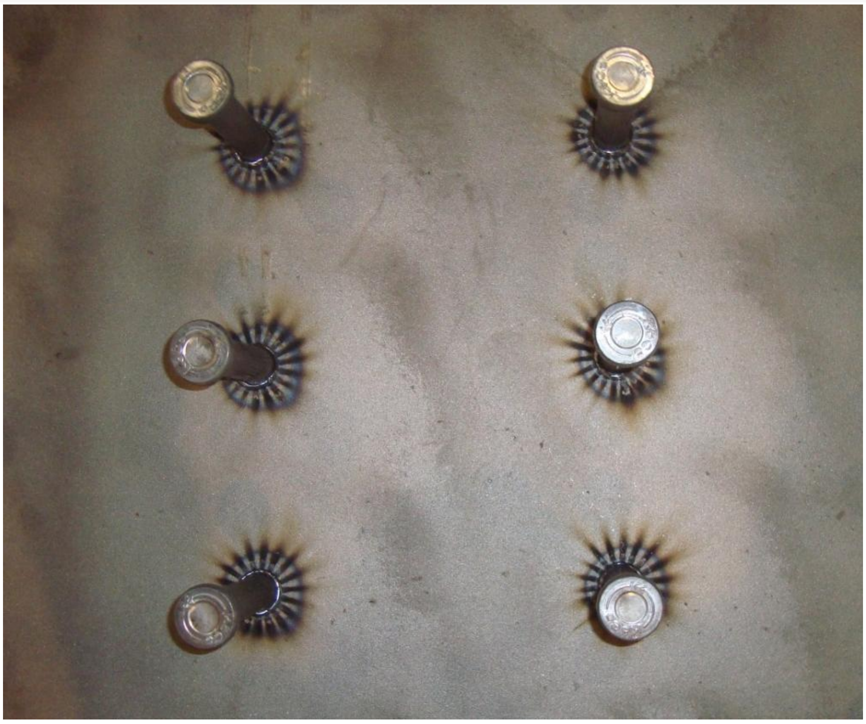

Guidelines for Composite Construction Including Stud Shear Connectors

Report No BS 115 (Revision 1)
April 2016

अअमासं RDSO
रेल अग्रदूत Transforming Railways
www.rdso.gov.in

Foreword to Revision 1

With the issue of BS 115, RDSO fulfilled a major requirement of field engineers regarding guidance on quality control and execution of works related to composite construction. But the document needs some updation based on feedback received. The feedback of Sh Pujari, ex-SSE/Inspection/RDSO and Sh Avadhesh from Panchsheel Fasteners was instrumental in necessitating this revision. The process/welder qualifications, surface preparation in case of painted surfaces and angle through which bending of stud during bend test is to be performed have been changed as per updated information available.

Feedback on these guidelines may be sent to RDSO on directorsteel2@gmail.com or edbsrdso@gmail.com.

Executive Director/ B & S/ RDSO
April 2016

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Foreword

Steel and concrete are most widely used construction materials for bridges these days. Both have their advantages and disadvantages. Steel is equally good in tension, compression and shear. Being a factory made/ fabricated structure, steel quality is better assured. But steel requires protection from effects of corrosion. Concrete, on the other hand, is good only in compression but is a versatile material that does not get affected by atmosphere that much. It can be poured and cast in the most efficient shape and consequently, it is cheaper as compared with steel structures. However, concrete is mixed and poured at site, so the quality and consistency concerns are more.

Composite construction aims to harness the good qualities of both steel as well as concrete. The load is carried by composite member with concrete taking only compressive load and steel taking tension as well as shear. The concrete deck shields the steel girder against rain/ sun, and hence corrosion is minimized. Further, for railways, concrete deck ensures that ballasted deck can be provided, which reduces maintenance requirement in track as well as the girder.

However, to harness the good qualities of both, the composite action needs to be ensured. For this, shear connectors are very important which transfer the horizontal shear between concrete and steel girder. RDSO has issued composite girder drawings since long and of late, their adoption in field has increased. Lots of field people have been referring different problems being faced during construction of composite girder to RDSO and so it was decided to issue comprehensive guidelines on this subject.

It is hoped that these guidelines will help field engineers in understanding the subject and in ensuring proper quality control. This is the first attempt to frame these guidelines and some errors/ discrepancies might have crept in. Feedback on these guidelines may be sent to RDSO on directorsteel2@gmail.com or edbsrdso@gmail.com.

Lastly, Sh V B Sood, Director/B & S/SB-II RDSO and Sh Sandeep Agrawal, ADE/SB-II/RDSO among other contributors deserve praise for their efforts to prepare these long awaited guidelines.

Executive Director/ B & S/ RDSO
December 2015

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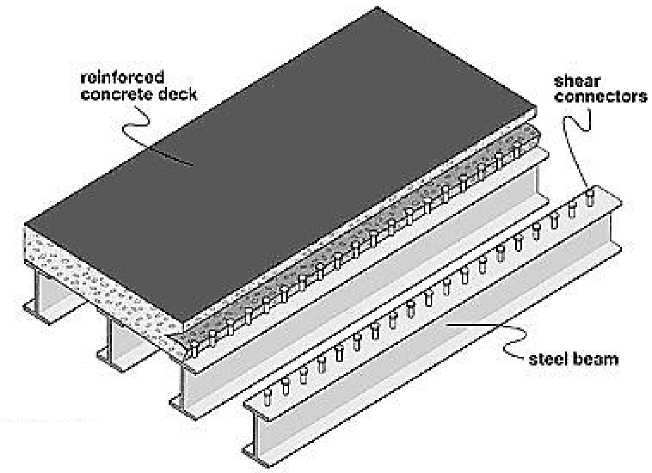
RDSO Guidelines for Fabrication of Composite Steel Girders including Stud Shear Connectors

1. **Introduction:** The beginnings of composite construction in steel and concrete may be traced to the patent "Composite Beam Construction" issued to J.A. Kahn in 1926 and to the earlier studies of R.A. Caughey published in 1929. Steel-concrete composite bridges provide an efficient and cost-effective form of bridge construction. With the adoption of automatic stud shear connectors, there are several advantages provided by composite girders (discussed subsequently) which have increased their popularity world over, and also on Indian Railways over the years. RDSO issued first drawings for composite girders in 1989. Initial drawings were with channel type shear connectors. Drawings with automatic shear studs are being issued since 2011.

Composite girder drawings for Road Over Bridges (ROBs) and for medium span railway bridges (upto 30.5 m span) are available which are being widely used. Currently, RDSO drawings for composite girders with steel plate girders and RCC deck are available for 25 T Loading 2008 for 12.2 m, 18.3 m, 24.4 m and 30.5 m spans, and ROBs of 18 m, 24 m, 30 m and 36 m spans. The floor system of Bow-String ROB girders also have composite action of slab with cross-girders.

2. **Some basic concepts of Composite girders:**

a) **Components and action:** Composite girders aim at taking advantage of properties of different materials. Steel, good in taking loads, is the main beam but to offset the problems of corrosion in steel and to provide ballasted track, RCC deck is provided at top. Concrete, being good in compression, participates as a structural member in compression for the main loads. Different components of typical composite girder are as follows:



- **Steel beams:** The steel beams may be rolled beams, rolled beams with cover plates or built-up sections. Indian Railways have so far designed and provided only composite girders with plate girders, however, composite girders with open web girders are also possible where the RCC deck can be at the bottom flange (Through or semi-through type) or on top flange (Deck type).

- **Reinforced concrete deck slab:** The reinforced concrete slab acts as a very effective cover on the compression side of the steel beams. This participates with the steel girder to take load in longitudinal direction. The slab is also subjected to bending loads in transverse direction.

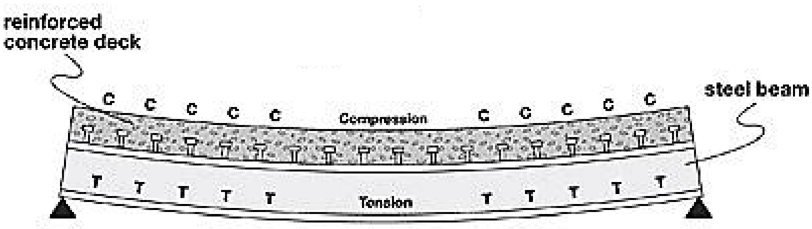
- **Shear connectors:** Shear connectors provide the necessary connection between the slab and the beams. Shear connectors provided must be capable of transferring horizontal shear at the interface between the slab and girders with very small deformations, i.e. with no appreciable slip between beams and slab, so that the whole structure deforms as a unit. Due to the presence of shear connectors, total load carrying capacity of a composite girder is higher than capacity arrived at by adding the strengths of steel girder and slab individually.

By utilizing the tensile strength of steel in the web/ bottom flange of girder and the compressive strength of concrete in the slab acting as top flange, the bending resistance of the combined materials is greatly increased and larger spans are made possible.

b) Advantages of Composite construction

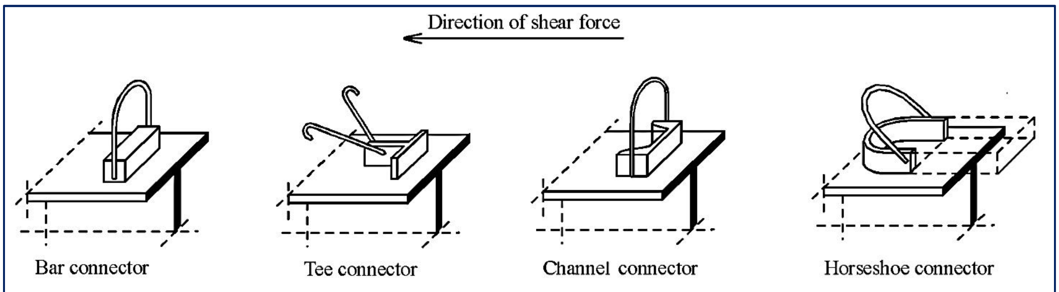
- Materials are used judiciously – Concrete for compression and steel for tension

- Steel is less fatigue sensitive due to more dead load and less effect of impact.
- Steel fabrication can be done in work shop. So, quality of workman ship is good.
- No temporary staging support from ground may be required for construction as the steel girder itself can provide support to staging.
- Shear studs can be provided through sheeting also, thus there may not be any need to remove the shuttering provided.
- Very fast construction can be achieved.
- Girders can be handled from many locations, which is generally a problem for concrete girders.
- Economical use of rolled sections for longer spans, which can reduce the fabrication efforts greatly.
- Composite structures possess overload capacity and toughness substantially in excess of the overload capacity and toughness of non-composite structures.
- Composite girders are more stable as compared to PSC girders due to lesser weight and easy shoring possible. This is especially important in structures like ROBs where trains are moving underneath while the handling of girders for insertion/ removal of bearings/shuttering etc.
- Rigidity of composite girders is higher which is advantageous for high speed train operations.



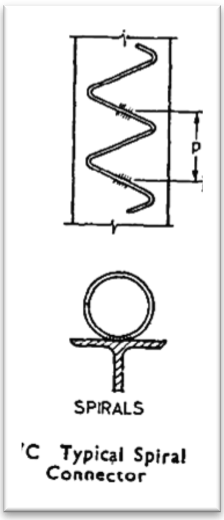
c) **Importance of shear connectors:** Shear connectors are the key component of a composite girder. Individually, both steel girder and the slab are capable of taking much lesser loads as compared to the loads carrying capacity of the composite girder. Bending of the girder under loads induces differential deflection in steel component and RCC component due to their different stiffnesses. This extra load carrying capacity is possible only because of the presence of shear connectors which enable compatibility of this deformation and hence the composite action is ensured by the shear connectors. Shear connectors have two main functions: (1) transferring horizontal shear at the slab/girder interface; and (2) resisting relative movements between the slab and the beams with as little movement as possible.

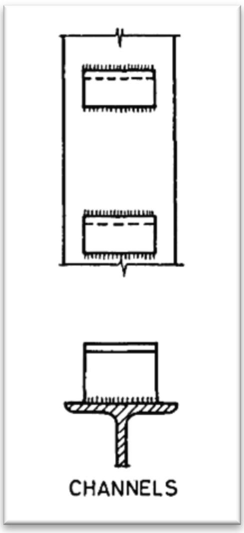
d) Different types of shear connectors: The shear connectors are of two types: Rigid and Flexible. The rigid type shear connectors take load through shear and these have very little deformation even at their ultimate load carrying capacity. This results in concentration of stresses in concrete/ welding near the shear connector. **For the heavily loaded structures like railways, these are not preferred due to their poor performance under fatigue.** Bars, Tees, channels etc can be used as rigid shear connectors, as shown in figure below:

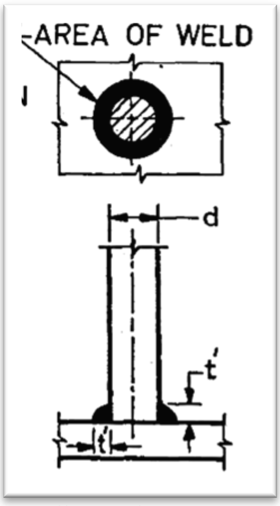


Rigid shear connectors (with hoops)

Flexible shear connectors take load through bending, shear and torsion at the connection of stud shear connectors with the parent steel. **The failure in the case of flexible shear connectors is not sudden as shear connectors are ductile and undergo large deformations before failure.** A variety of material like headed studs, channels, rebars, etc can be used as flexible shear connectors.







Fillet welded stud

Studs can be welded using normal fillet weld also, as shown above. This type of welding was earlier used on Indian railways but has been discontinued in latest RDSO drawings. The headed studs with automatic stud welding process (shown in figure alongside)have been specified in latest RDSO drawings and are most commonly used on Indian Railway bridges because of several advantages which are discussed subsequently.

There are several new types of shear connectors such as Perfobond ribs, T-rib connectors, waveform strips, pyramidal shear connectors etc which have been tried for composite construction. These are, however, not yet used on Indian Railways.

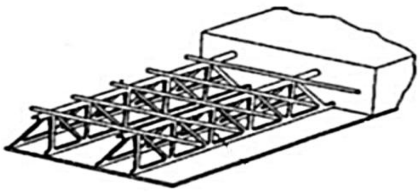


Fig 7.Pyramidal shear connector

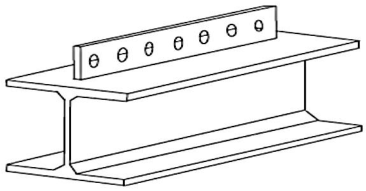
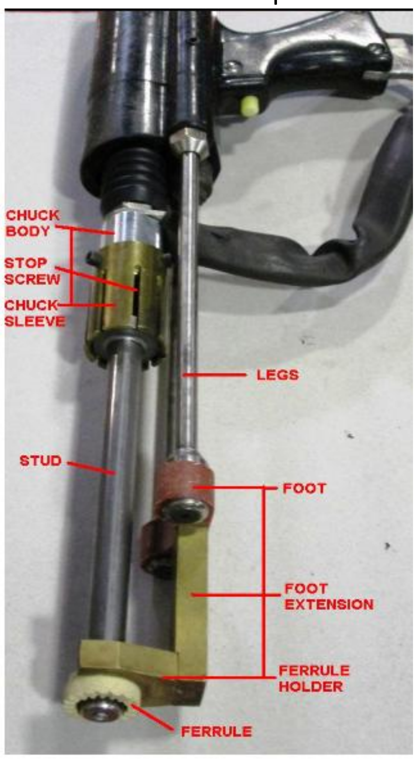
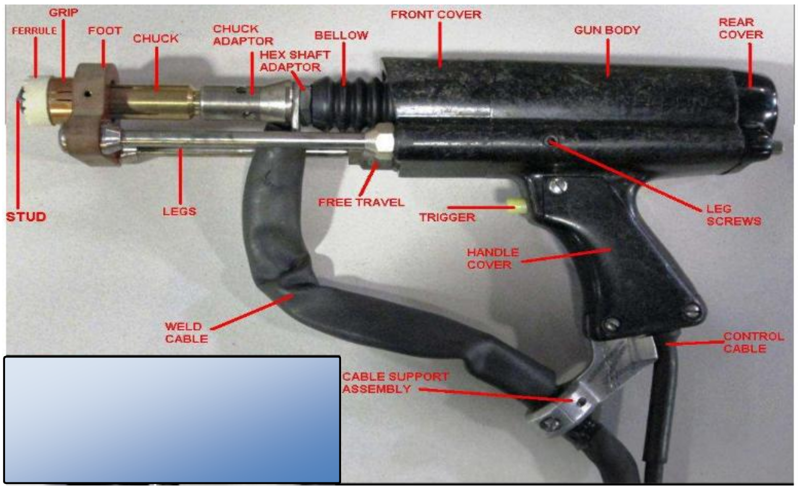


Fig 3.Perfobond ribs shear connector.

3. **Automatic Stud welding process:** In automatic stud welding, arc welding is used to join stud to steel member. The arc is created between tip of the shear stud and the steel member by creating a large potential difference between the two. The tip of shear stud needs special treatment to initiate the arc. The process itself is required to be controlled so that the proper profile of weld connection is created.

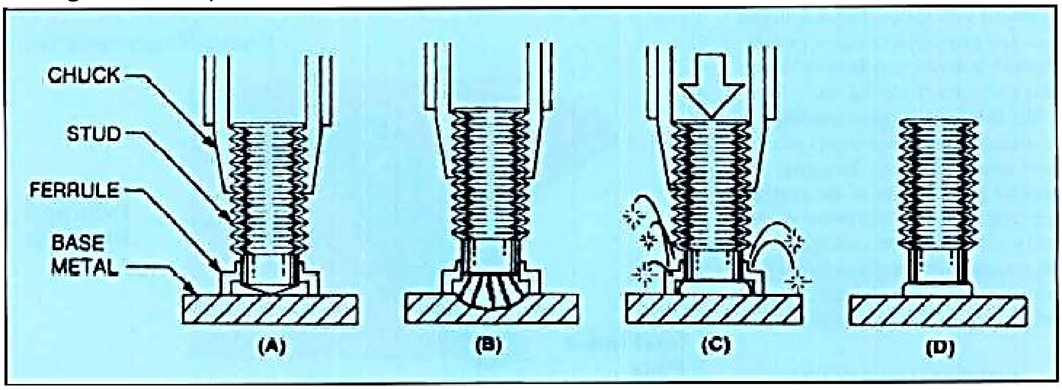


- **The Process:** Electric arc stud welding involves the same electrical, mechanical and metallurgical principles found in any other arc welding process. In stud welding, the amperage and the arc duration are controlled through power source and stud welding control system. To create the proper distance between the stud tip and steel member to initiate the arc, a lifting mechanism is there in the gun to draw the stud away from the base material. The arc is shielded from atmosphere through a ceramic ferrule which also gives shape to the weld profile. The gun includes a stud-holding chuck, two legs, a foot piece and a ferrule holder to hold the ceramic ferrule, as shown in figure alongside.



Another view of stud welding gun

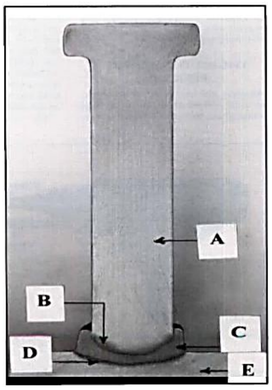
The sequence of operations for stud welding is as follows (The stages are also shown in figure below):



A. A stud and ferrule are loaded into the gun, and the gun is properly positioned against the member.
B. The gun is pushed against the base material taking up the plunge, or stud length available for burn off against the gun spring pressure. The trigger button is depressed to start the fully controlled automatic sequence. This sequence consists of initiating the weld current, and lifting the stud to create an arc by energizing the gun solenoid.
C. The arc duration time is completed and the stud plunged into the molten pool by means of a spring when the gun solenoid is de-energized and turning off the weld current at the end of the weld cycle.
D. The weld is completed and the gun is lifted off the stud and the ceramic ferrule broken off by hitting with hammer. The installed stud is inspected for weld quality.

A completed weld cross section is shown in figure alongside. The various parts of a welded stud are as follows:

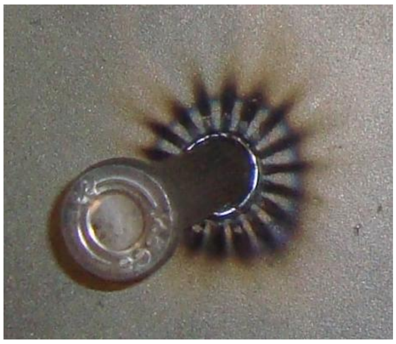
A:Heat Unaffected stud material,
B: Stud Heat Affected Zone (HAZ),
C: Cast zone,
D: Base Material HAZ,
E: Heat unaffected base material.



The automatic stud welding is characterized by the following:

- When a proper weld is made by the automatic stud welding process, the weld is stronger than either the stud or the base material and **failure shall be in stud or base material.**
- The fasteners for electric arc stud welding have a special shape and/or flux on the tip of the stud that is to be welded. This shape/flux initiates and improves starting of the welding arc and stabilizes the same. Flux may also serve to deoxidize the molten weld metal for a sound, low-porosity weld zone to produce a full penetration weld.

- **Ceramic ferrules or ceramic arc shields** serve several functions. First, they contain the pool of molten metal and form it into the fillet (flash) around the periphery of the stud. Second, they control to a great extent the amount of arc brightness and the quantity of sparks expelled during the weld. Third, they are designed with specific vent patterns so that when the arc is initiated, the flux in the stud end is consumed and deoxidizes the weld zone by expelling weld gases through the vents, thus preventing oxygen from entering the weld area.



Ferrules are available in a wide variety of configurations to allow studs to be welded to round tubing and bars, plate edges, channels, struts, rectangular and square structural tubing edges. These various configurations also allow for a number of weld positions other than downhand.

It is important to keep the ferrules dry. If they absorb too much moisture, the weld instantly turns the moisture into steam with a substantial amount of molten metal expelled. In addition to the possible danger from this “explosion,” the weld is made very porous and weak. Ferrules that have been wet or have absorbed moisture can be dried by heating them to 250^0 F (121^0 C) until the moisture is gone.

- **STUD WELDING EQUIPMENT:** In the basic process, DC power from a self-contained generator or transformer/rectifier is passed through a stud welding control system. The control system is set at a determined time, voltage and amperage to initiate the arc which forms the molten pool. The remaining unmolten stud shank is then plunged into the molten metal pool.

Systems are available for welding studs with diameters ranging from 1/8 to 1.25 in. (3 to 32 mm).In recent years, the stud welding industry has been transformed from mechanical to solid state welding equipment with closed-loop controls that have contributed significantly to simpler weld setups and better weld quality. These solid state controls provide verification of both weld time and current. Current controls can adjust for weld cable resistance, compensate for incoming power fluctuations and provide system shutdown in the event of variations from the set weld parameters.

The important parameters of an automatic welding procedure are given below:

- **Plunge** is the length of the stud that protrudes beyond the ferrule. This portion of the stud is available to be "burned off'" or melted, to develop the weld fillet. Plunge is a physical measurement set and measured with the stud and ceramic ferrule in place on the stud gun.

- **Lift** is the distance the gun pulls the stud away from the base material. Before the weld is started, the stud and base metal are in contact. Lift creates an air gap that the electric current must bridge. The current flow across the resistance of this gap creates the arc heat to melt the stud and base material. Lift is physically set on the stud gun and is measured when the stud weld is initiated. Lift should be set and measured by placing the stud and ferrule on a non-conductive surface and initiating the weld cycle so that an actual molten weld is not made.

- **Time** is the duration of the weld. On thin base material, a shorter time and higher amperage can be used to achieve sufficient heat and prevent melting through the base material. On some base materials, a longer time and low amperage improve the ductility of the weld zone. Weld time is set on the time setting indicator of the control system.

- **Amperage** is a measure of the current from the power source that flows across the air gap created by the lift. Increasing the amperage increases the weld heat. As with the time setting, a higher amperage setting is needed for larger stud sizes. Amperage is also set on the control system's current setting indicator.

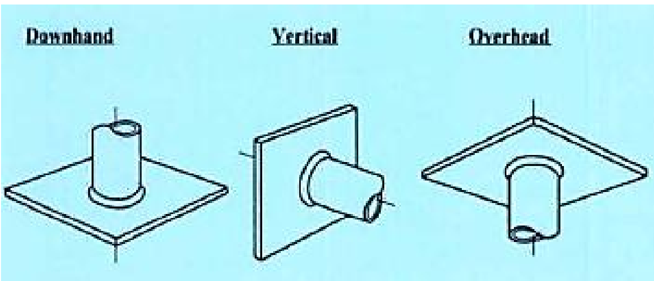
- **Alignment** is the proper centering of the stud in the ceramic ferrule so that the stud does not contact the ceramic ferrule during lift and plunge. In absence of proper alignment control, binding can occur. Binding can inhibit both stud lift and stud plunge so that there is less than sufficient stud melting and less than full penetration into the molten weld pool, resulting in a less than full strength weld.

- **Advantages:** Stud welding has many advantages over other joining processes:-
  i. **The heat imparted to the base material in this process is minimum.** This ensures that there is little distortion of the base material. Thus it can be used for welding studs after the girder is ready by welding the flanges and web.
  ii. **Automatic stud weld is strong.** Unlike the fillet weld all around, that would be used to weld a bolt in place, a stud weld is a full cross sectional weld. This means that full face of the fastener is welded in place providing a strong, worry-free weld.
  iii. **It is a fast process.** Welding a 20 mm diameter fastener will take less than one second.
  iv. **It is single sided.** This means that access to the other side of the work piece is not required.
  v. **Requires no special skills on the part of welder** and little training to install.

- **Disadvantages:** Stud welding has the following disadvantages:
  i. **The current required is quite high** and requires a stable connection/ generator which can provide that much current. It is sometimes difficult to get such connection in field.
  ii. **The studs are required to have special metallurgy, especially at the tip.**
  iii. If the studs are welded in workshop, these have to be protected from distortion/ **damage during transit and handling by cranes** etc.

4. **Settings of Stud Welding Process:** To ensure proper quality of welds in automatic stud welding procedure, the following aspects require attention:

- **Proper Position of Welding:** As with normal welding, studs can be welded in different positions such as downhand, vertical and overhead etc, as shown in figure below. Studs of all weld base configurations and diameters can be easily welded in the downhand position. In most applications on Indian Railways, it is possible to weld studs in downhand position.



The vertical/ overhead positions cause an increased amount of welding sparks to fall during welding and suitable operator protection is needed. Special spark retention accessories available from the stud manufacturer shall be deployed to control the weld sparks. Vertical and overhead welds require extra precautions and **it ispreferable that the stud be welded in downhand position even by manipulating the members, if feasible and convenient.**

As a general rule, studs up to ¾ in. (19mm) in diameter can be welded in a vertical position with consistent full strength results. Special ceramic ferrules are used with studs 5/8 in. (16 mm) and larger when welding to the vertical position of the plate.

- **Proper Weld Plate Cleanliness:** An important parameter to ensure weld quality is the cleanliness of the plate on which studs are to be welded. Normally this is the top flange of the composite girders. Before starting welding of studs, the top flange should be as clean as possible. **The cleaning shall be done so as to remove heavy mill scale or heavy, flaky rust, as well as any deleterious coating such as heavy oil, paint, galvanizing, grease and moisture.**

For providing studs, the member surface shall be cleaned by light sand blasting or by scraping with wire brushes such as to remove the mill scale. If grease or other contaminants are present, the surface shall be cleaned with solvents also. **The prepared surface shall not be painted or metallised in any way.** Where studs are to be welded to steel surface already painted, the weld surface should be brushed, ground or scraped to completely remove the paint from the weld locations. **It is not adequate to remove enough paint to make electrical contact and allow the weld arc to get started, since the thickness and volatility of the remaining paint may still have a serious adverse effect on the welds.** The surface on which studs are to be welded shall be free from paints for a distance of minimum 50 mm from the center of any stud to be welded.

Appearance of light rust does not affect the performance of the stud welding process. However, if the surface has become heavily corroded, cleaning shall be done again. Another requirement is that **weld splatter, ferrule pieces etc should be removed from the plate surface** so that the stud contact with the weld plate is clean and even. This will ensure good electrical contact and current flow.

Earthing connections may be provided by screw type "C" clamps, fast action spring clamps, or lever action hold down clamps mounted to the member being welded. **The spot where clamp is provided for earthing should also be cleaned on both sides of the plate** so that a good current path is established. **Earthing spots can be cleaned very quickly with an abrasive wheel, wire brush etc.**

If required for corrosion protection, the steel surface duly fitted with studs shall be aluminium metallised <u>after welding of studs and their inspection is over</u>. However, the same **shall not be painted** as this would reduce the bond strength with concrete which is to be poured subsequently.

- **Restriction on Galvanizing/ Other coatings on Studs:** Zinc/ paints etc may contaminate the weld metallurgy. **No galvanized/coated studs shall be used on Indian railways.** Good quality concrete of slab shall provide the necessary corrosion protection to the studs.

- **Checking Drawings:** Before start of work, the drawings shall be checked to see if the same are OK. The following shall be verified:

    - **Proper Weld Plate Thickness:** The setup requires checking the combination of stud/ plates being used. To develop full steel tensile and shear capacity of the stud, plate thickness shall normally be at least 0.5 times the stud shank diameter. For welding plates thinner than this, extra care is required to be exercised in distortion control. For 25 mm dia studs normally used on Indian railways, distortion will not be an issue for plates thicker than 12 mm.
    - **Proper Edge Distance:** Studs should be placed no closer to a base plate free edge than the stud diameter plus 1/8 in. (3 mm) to the edge of the stud base. This distance should be at least 1 to 1.5 in.(25 to 38 mm) from each free edge.

5. **Selection of Stud Welding Operator:** The stud welding operators are important to ensure timely and proper execution of work. Inexperienced welders are likely spoil lots of welds, causing loss as well as delay in the project. The site engineer shall ensure that the welders being deputed for work are aware of the following:
    - Knowledge regarding general principles of the process, proper equipment setup, weld setup for the studs, general guidelines, and other literature.
    - Knowledge regarding precautions to be taken during stud welding and
    - Procedure for visual examination of welds done to determine if the same is satisfactory or requires further investigation.
    - Possible reasons for the poor weld being formed and remedies for the same.

6. Quality Assurance Procedure to be adopted:

MATERIAL QUALITY ASSURANCE

A. **Studs:** Studs shall be made from steel conforming to ISO-13918. RDSO drawings have specified SD1 material to be used as per design. Chemical and Mechanical characteristics of finished stud material are as follows[1]:

Symbol	Material/Material group/Property class	Standard	Mechanical properties of the finished stud[2]
SD1	Material Group 1 with the limits C $\leq$ 0.2%* CEV $\leq$ 0.35* Al $\geq$ 0.02%*#	ISO/TR 15608	$R_m \geq 450\ N/mm^2$ $R_{eH} \geq 350\ N/mm^2$ $A_5 \geq 15\%$ Where R_m is the tensile strength of steel@, R_{eH} is the upper yield of material and A_5 is the percentage elongation at fracture as per ISO 6892-1/ ISO 13918.

**Values from the ladle analysis*

 # If other elements for killing are used, they shall be reported in the inspection document

@ The tensile test to be used shall be a full-size tensile test. However, if the dimensions of the studs do not allow a full-size tensile test, the test may be carried out on the raw material provided the mechanical properties corresponding to those of the current part of the stud are not modified by the manufacturing process.

If tensile testing is not possible, a hardness test shall be carried out for ferritic materials, thus determining the tensile strength in accordance with ISO 4964. The particular properties of the cold-formed material, especially in the peripheral zone, shall be taken into account. For cold-formed studs, the mean value of a minimum of three test points shall be determined, whereas the whole cross-section shall be included. This means value shall achieve at least the tensile strength according to ISO 6892. For the rest, the mechanical properties of the raw material shall be used.

Quality of studs shall be assured as follows:

- The stud supplier shall submit mill test certificate regarding the steel.
- **Additional tests to confirm the metallurgical and physical properties of the stud material from government approved laboratories may be done if number of studs is more than 10,000 @ one per 20,000 or part thereof.**

[1]Para 5.3.3.2 of ISO-13918

[2]The mechanical characteristics should be as per ISO 6892-1.

Special Note: *The chemical composition of IS:2062 E450 steel is quite close to the above steel but the maximum Carbon Equivalent is only 0.52 whereas EN code requires maximum Carbon Equivalent of 0.35. Therefore steel to IS: 2062 E450 is not suitable for studs.*

- **Mass:**Mass of stud shall be as per table A.4 of ISO 13918:2008(E). For 25 mm diameter shear connectors (SD) with different lengths, mass values in the table are as follows: #

Nominal length of stud*	Mass in grams[3]
150	66
175	76
200	85
225	95
250	105

**It is the design value of the welded stud. The loose stud shall be longer than this. For special conditions, e.g. through-deck stud welding, length will be shorter.*
#Due to the tolerances, the values of mass are only approx. (specific weight = 7.85 Kg/dm^3)

B. **Tolerances in Length:**[4] The length of loose studs shall be verified as per EN code provisions. For 25 mm, 200 mm long studs commonly used in RDSO drawings, the length of loose stud shall be 205.5 mm, with a tolerance of ±1.5 mm.

C. **Stud tip and flux:** The tip shape of the shear connector may be chosen by the manufacturer. The stud tip is supplied with flux in the form of a press-fitted aluminium ball or aluminium spray coating.

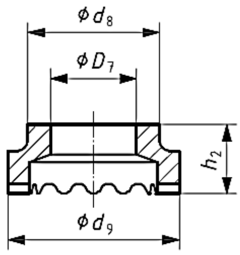
D. **Ceramic Ferrules:** Compatible ferrules for the studs shall be brought for welding the studs. The dimensions (of 25 mm studs used in most RDSO drawings) shall conform to the following[5]:

Dimensions of ceramic ferrules for unthreaded studs and shear connectors

Dimensions in millimetres

Form	$D_7{}^{+0,5}_{0}$	$d_8 \pm 1$	$d_9 \pm 1$	$h_2 \approx$
UF 25	26,0	35,5	41	21

a At the manufacturer's discretion.



MACHINE/ PROCESS QUALITY ASSURANCE

E. **Welding Machine Qualification:** Any machine, whether running with transformer on 3-phase AC or single phase AC or running with DC generator can be used provided its rated current output is adequate for welding the diameter of studs being provided. The welding machine settings for making a weld shall be specified by the stud manufacturer.

[3]Table A.4 of BS EN ISO 13918:2008
[4]Table 10, Figure 5 of BS EN ISO 13918:2008
[5]As per para 10.3 of BS EN ISO 13918:2008

Typical requirement of current for downhand welding for 25 mm dia. Studs used in design by RDSO are:

Diameter of stud in mm	Current (Amp)	Time		Lift (mm)	Plunge (mm)
		Sec	Cycles		
25	1900	1.4	85	0.125	0.250

The above current and time values are indicative only for a particular machine. It is the responsibility of the welding machine supplier to recommend the welding process/ parameters to be adopted.

F. **Process Qualification:** The welding parameters and the welder shall be qualified. For initial qualification, minimum two studs of each type being used (total minimum 17)[6] shall be welded on sample plates having similar properties to the girder part on which these studs are to be provided. The studs shall be welded in same position as to be welded in the actual girder part. These studs shall be checked for quality as per sub-para (K) below. If these studs are not found satisfactory, the welding parameters shall be adjusted or welder shall be further trained and sample studs provided again till welding is found satisfactory. After satisfactory qualification, certificate shall be issued by an officer of level of Assistant Engineer or above, which shall be further governed as follows:

(i) The qualification shall be valid for two years and after that the welder shall be qualified again by following same procedure.

(ii) For any new position /quality/size of stud, the parameters to be used are required to be qualified only once. This need not be re-verified as long as the quality of studs is satisfactory in field.

<u>QUALITY ASSURANCE DURING EXECUTION:</u> (Proforma for inspection of welded shear studs is at Annexure I.)

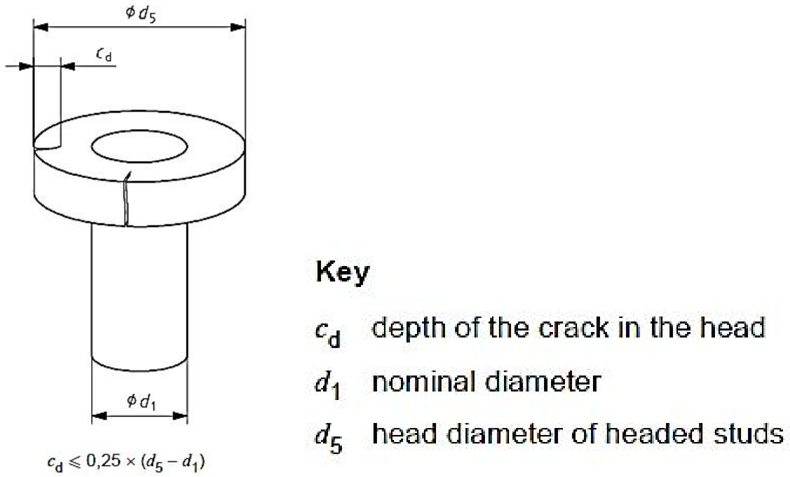
G. **Surface preparation:** The quality assurance shall be as outlined in para 4 above. The surface of member on which studs are to be provided shall be certified to be Ok by the site engineer in charge of his representative before welding is taken up.

H. **Inspection of studs:** The raw material inspection as per sub-para (A) above shall be done on studs during supply. Even during execution of work, few sample studs shall be inspected randomly by inspecting officials:

(i) Dimensional check of studs shall be as per requirement.
(ii) The studs shall have proper flux at the tip.
(iii) Studs shall not be corroded and also these shall not have any coating.

[6] Ref: Para 10.2.4 & Table 1 of ISO 14555:2006(E)

(iv) Completed studs shall be free of defects which can affect the application. Cracks in the head shall be permissible, but may not exceed the value given in figure below[7]:



Permissible head cracks for shear connectors

I. **Visual Inspection of Ferrules:** The raw material inspection as per sub-para (A) above shall be done on studs during supply. Even during execution of work, few studs shall be inspected randomly to ensure that

i) Ferrules are not be broken/damaged.

ii) Ferrules are dry.

iii) If Ferrules have been wet or have absorbed moisture, these can be dried by heating them to 250^0 F (121^0 C) until the moisture is gone. Only dry ferrules shall be used for work.

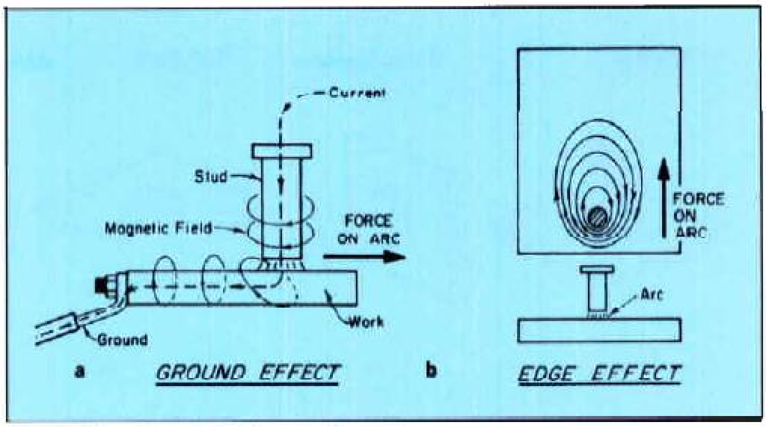
J. Action to be taken if proper weld is not achieved:

a. **Machine settings:** After setting the plunge/ lift and time/ amperage as per recommendations, few trial welds shall be made to see if proper welds are being made. If any problems are noticed, the time and amperage settings shall be adjusted.

b. **Proper Alignment:** The machine shall be checked for proper alignment control by observing the movement of the chuck/stud before starting the work with a mchine. **This aspect may be seen if proper welds are not possible to be made with a particular machine despite using proper settings.**

c. **Problems due to Grounding/Arc Blow:** A very important parameter which affects the weld quality is the uniformity of current around the stud. The welding arc is electromagnetically deflected toward the grounding point or toward the larger mass of the base plate configuration being welded. The figure below shows the ground and edge effect patterns due to arc blow.

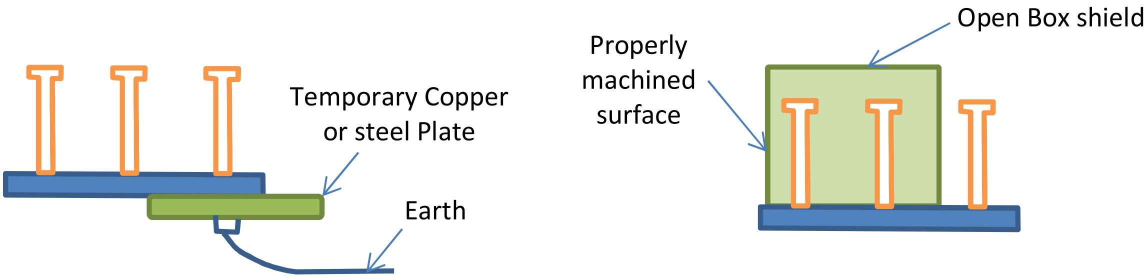
[7] As per ISO 13918:2008(E).



Effect of (a) Ground connection, and (b) Workpiece on distortion of magnetic field

Typically, the effect of this non-uniformity is that there is a lack of fillet weld on the periphery of the stud opposite the direction of the arc blow. This can adversely affect weld strength and quality. In multiple rows of studs in a composite girder, the middle row often has excellent weld whereas the side rows exhibit problems due to arc blows.

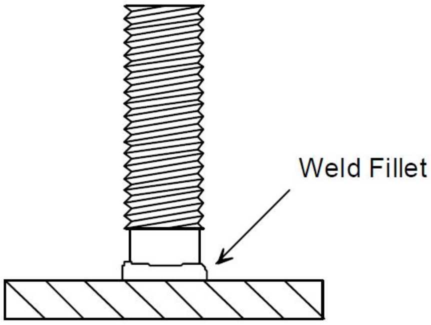
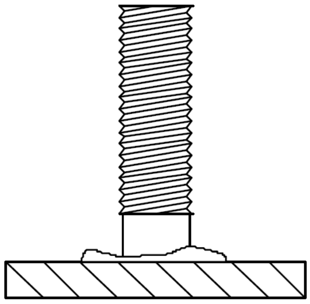
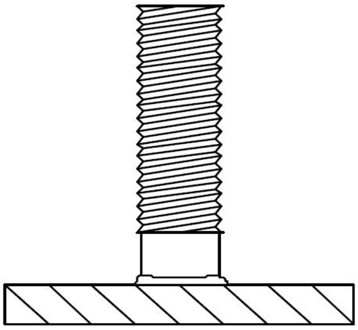
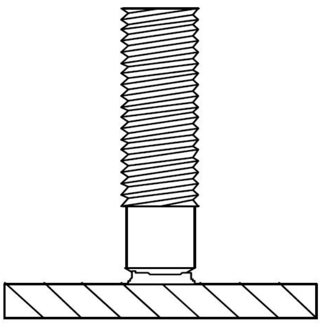
To eliminate the problems associated with these effects, the following measures can be taken: **Either a copper or steel plate larger than the base plate to be welded, with a center ground bolted to the bottom, can be provided temporarily below the base plate to increase the edge distance available. Or an open box shield shall be provided around the stud welding location. The bottom of this open box shall be properly machined so as to have good contact with the base plate. This will provide path to current and eliminate the grounding/ arc blow effects.**



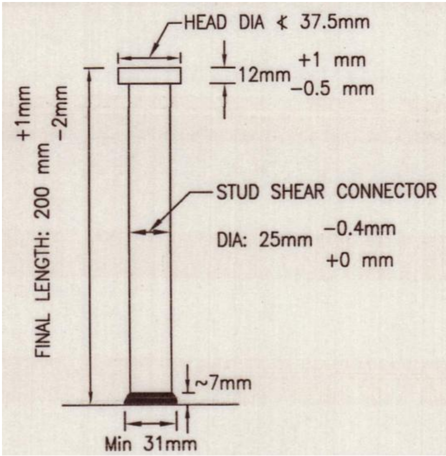
Remedies for grounding/ arc blow defects

K. **Inspection of completed weld:** During welding, used ferrules shall be broken by hammering and the welds shall be inspected to ensure that quality is good.

(i) **Visual inspection of shape of weld:** Visual inspection of the profile of weld collar is a very good indicator of the quality of the entire process. Guidance may be taken from the illustrations and causes for getting these shapes tabulated below:

Shape of Weld Achieved	***Remarks/ reasons for the shape***
 GOOD WELD	A **good weld** is characterized by a clean even fillet of good height all around (360^0) the weld stud. The fillet should be **bright and shiny with a bluish color** It shall have a slight flow of metal into the base material from the bottom to the fillet.
 HOT WELD	**Identification:** Diameter of collar increased and height of collar reduced. **Reason:** Excessive current **Remedial Action:** Decrease time, power or both
 COLD WELD	**Identification:** Diameter of collar reduced or incomplete. **Reason:** Too little plunge **Remedial Action:** Increase time, power or both
 HANG UP	**Identification:** Stud base is partially melted away. **Reason:** Stud rubbing the ferrule **Remedial Action:** Stud be exactly centered in the ferrule

(ii) **Dimensions of Welds:** The dimensions of 5% welds shall be measured and verified against the required dimensions. Typical dimensions with tolerances as per some RDSO drawing, are as follows:



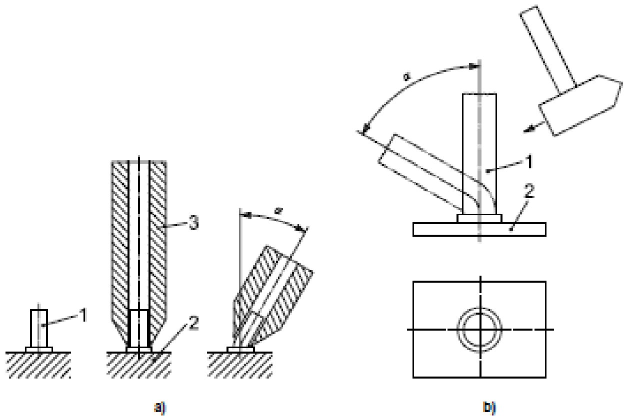
- The length of weld which is not fused properly or which has improper dimensions shall be noted. The weld collar is a butt weld and a slight variations in the height of collar are normal and don't affect strength of the weld as long as the proper fusion of the stud with base metal is there. No action shall be required for these.
- Occasionally, isolated studs might have reduced collar width/ porosity/ lack of fusion. These defects shall be noted along with the length of weld affected. **Any stud with cumulative weld-defect length less than 10% of the circumference shall be considered acceptable and no action shall be taken.**
- **Any stud with cumulative weld-defect length within 10% and 20% of the circumference shall be considered 'repairable'** provided that clustering of such repaired studs does not exceed:
  a) 1 in 6 in end quarter span.
  b) 1 in 3 in middle half span.
- **If the defective weld clustering is more than above limits, the studs shall be considered 'not repairable'. Any stud with cumulative weld-defect length more than 20% shall also be considered as 'defective and not repairable'.** All defective/ non-reparable studs shall be replaced with good quality studs of same diameter/ length.
- For repairs/ replacing studs, paras L, M and N below shall be referred.

(iii) **Verticality of studs:** Studs shall generally be vertical. If welded studs are inclined, process needs to be checked. Slightly inclined studs having good welds as per para (ii) above shall be considered acceptable. But generally, inclined studs will have problems of fusion etc and the process might not be completed properly. The problem with machine that is leading to inclined studs will generally need to be addressed.

(iv) **Burn-off Length:** This is an additional check on the quality of the whole process. For 25mm diameter, 200mm length which is commonly used in RDSO drawings, the burn-off length is 5.5 mm[8]. For measuring this, a loose stud shall be placed next to a welded stud and difference in height shall be noted. Incorrect burn-off length will also be shown in the shape of the weld. The weld shape and burn-off length together will help in diagnosing problems with the process/ quality after which necessary corrective action can be taken.

(v) **Ring Test:** 1 in 20 (5%) studs shall be tested by bend test. It involves striking the side of the head of the stud with a 2 Kg hammer. A ringing tone achieved after striking indicates good fusion whereas dull tone indicates a lack of fusion[9].

(vi) **Bend Test:** 1 in 100 (1%) studs shall be tested by bend test. The test consists of bending the studs after they are allowed to cool, to an angle of approximately 60^o from their original axes by either striking the studs with a hammer on the unwelded end or placing a pipe or other suitable hollow device over the stud and manually or mechanically bending the stud as shown in figure below:



LEGEND[10]
1-stud,
2-work piece,
3-bending tool,
α-Angle of bending

The bending shall be done in the direction opposite to any arc blow or visual imperfection in the weld[11]. At temperatures below 10^o C, bending shall preferably be done by continuous slow application of load[12].

L. **Repairs of Repairable defective Studs:** Studs identified to be 'repairable' as per para (I) above by the site engineer, then it shall be repaired by 6mm size fillet weld of good

[8] Table 10, Figure 5 of BS EN ISO 13918:2008
[9] Para 5.5.4 (a) of BS 5400: Part 6: 1999.
[10] Part of figure 1 of ISO EN 14555: 2006
[11] Para 11.3(a) of ISO 14555:2006(E)
[12] Paras 7.6.6.1 and 7.7.1.4 of AWS D1.1/D1.1M: 2004

quality taking care in surface preparations and execution as per clause no 26.6 of IRS B1-2001.

M. **Remedy for non-repairable defective studs:** Studs identified to be 'non-repairable' as per para (I) above by the site engineer, whether due to extent of defect or due to population of such defective welded studs, may be allowed to remain as it is and equal nos of additional studs of same quality shall be provided as near to defective studs as possible, leaving at least 50mm gap between studs to ensure space for reinforcement and good quality concreting. If the defective studs are clustered together, or space for providing additional studs is not available, then few studs may be cut by gas/saws. **The studs shall be cut around 20mm from the base to ensure that the base material is not affected.**

N. **Rejection of Member:** If the population of defective welds is excessive and providing additional studs and/or cutting of studs as specified above is not desirable from quality considerations, then the member shall be rejected.

7. References:

a. **Static Strength Of The Shear Connectors In Steel-Concrete Composite Beams - Regulations And Research Analysis,**By Slobodan Ranković, Dragoljub Drenić, Facta Universitatis Series: Architecture and Civil Engineering Vol. 2, No 4, 2002, pp. 251 – 259.

b. **Various types of shear connectors in composite structures: A review**, ByImrose Bin Muhit, Composite Structures Lab, Chung-Ang University, Seoul, KOREA.

c. **Principles and practices of stud welding**, by Harry A. Chambers

d. **Steel-concrete composite bridge design guide**, NZ Transport Agency research report 525, September 2013.

e. **BS 5400: Part 6: 1999**, Steel, concrete and composite bridges, Part 6. Specification for materials and workmanship, steel.

f. **IRS B1: 2001**, Indian Railway Standard specification for fabrication and erection of steel girder bridges and locomotive turn-tables(fabrication specification)

g. **AWS D1.1/D1.1M: 2004**, Structural Welding Code – Steel (American National Code)

h. IS: 3935-1966, IS:11384

i. EN 1994-2:2005, BS EN ISO 13918:2008, ISO/TR 15608:2005, ISO 6892-1:2015, ISO EN 14555: 2006(E)

j. Technical literature on studs, ferrules and welding machine from manufacturers collected from internet: **M/S Nelson Stud Welding Inc,** Ohio, USA, **Image Industries Inc,** Wood Dale, Illinois, USA, **HBS Bolzenschweiss - Systeme Gmbh & Co,** Dachau, Germany

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Annexure I

Proforma for Quality Assurance for Inspection of Automatic Stud Welding

General Data

Name of Inspector ________________________________, Date of Inspection: _______________

Fabricating Agency: ____________________________, Workshop ____________________________

Drg. No. ___________________________, Span no. _________, No. of studs per span_________

Approved QAP No _________________________, Dia. Of stud : _______, Length of stud: ______

Inspection Results(If answer to any question is NO, then the process needs to be checked and inspection to be repeated)

1. **Studs Material Inspection Report** Nos____, Satisfactory? Yes/No
2. **Ferrules Material Inspection Report** Nos____, Satisfactory? Yes/No
3. **Name of machine operator**: __________________, **Date of qualification** of operator by officer: Certificate No______________________; Date_______ (Not more than 2 years old Yes/No)
4. **Machine brand/serial no used for welding**: __________________________________
5. **Machine settings (As per approved QAP or approved qualification record):**

Current	Duration	Cycles	Lift	Plunge	Special settings, if any

6. **Surface preparation**(100%):
   a) Is surface free from rust/mill scale etc? Yes / No
   b) Is surface free from grease/paints etc? Yes / No
   c) Is the surface being cleaned of weld splatter/ broken ferrules during welding: Yes/No

7. **Visual Inspection of raw material** (on random samples, ~2-4%)*(Only summary to be given here, Separate register may be made for detailed record)*
   a) Studs
      (i) Is surface free from paint, galvanizing, grease and moisture: Yes / No
      (ii) Is the flux intact at the tip of the stud: Yes / No

(iii) Is the length of stud as per requirement: Yes/No

b) Ferrules:

(i) Are ferrules broken? Yes / No

(ii) Are the ferrules properly dry Yes / No(With Over drying/ Without Over Drying)

c) **General Remarks** on storage/ handling of materials etc__________________

____

____

8. **Ring test**(@5%): *(Only summary to be given here, Separate register may be made for detailed record)*

No. of tests done___________ Results: NosOK_____________, Nos NOT OK ___________

9. **Bend Test**(@1%): *(Only summary to be given here, Separate register may be made for detailed record)*

No. of tests done___________ Results: Nos OK_____________, Nos NOT OK ___________

10. **Visual Inspection of completed weld** (@100%): *(Only summary to be given here, Separate register may be made for detailed record)*

a) Is the surface of flash having a shiny bluish hue?Yes / No

b) No of studs with good weld shape?____________

c) No of studs with defects within acceptable limits?____________

d) No of studs with repairable defects?____________

e) No of studs defective/with not repairable defects?____________

11. **Measurement of Welded Stud Height**(@5%): *(Only summary to be given here, Separate register may be made for detailed record)*

a) Height of welded stud: ____________ mm, Burn Off Length _____________ mm

b) Is the burn-off length proper? Yes / No

12. **Is the member with studs acceptable?**Yes/No

13. Changes required in welding process in light of defects observed, if any _______________

____

____

____

Repairs of Defects (If possible)

a) Total Repairable Studs: Nos. _______________

b) Date of repair: ______________

c) Quality of repairs: OK / NOT OK

14. Replacement of Non Repairable studs (If possible)

a) No of Non-repairable studs: ___________________

b) No of additional studs provided: ___________________

c) No. of studs cut: _______________ nos.

d) Additional studs provided (with 50mm gap all around): _________ nos.

e) Quality of new studs: OK / NOT OK

-0-0-0-0-0-0-