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FEA Based Strength Analysis of Weld Joint for Curved Plates (Overlap) Specially for Designing Pressure Vessel Skirt Support

M. V. Dalvi, Vinay Patil, R. S. Bindu

Abstract: Weld joints form an important part of pressure vessels, they are highly essential for structural integrity of the system. Typical welds are done on flat surfaces and their strengths are well catalogued for reference. If a lap joint is required for longitudinal plates, the reference for taking overlap length is available. When a lap joint is required for curved plates, no reference is available for it. The objective of the project is to form certain set of guidelines or set of formulations which will serve as a guideline for overlap length in lap joint of curve plates.

Analysis type for this will be Structural Non Linear Finite Element Analysis i.e. by using ANSYS 12.0 Workbench for modeling and ANSYS 12.0 for Structural Non Linear Analysis. No of Estimated Analysis conducted is 53 for three different cases of analysis.

We have studied by analysis and experimentation of 03 cases, for which we required to conduct 53 analyses. After this analysis, experimentation results and their comparison we have to make the conclusion or forming certain set formulations which will serve as a guideline for welds of curve plates with an overlap.

Keywords: Lap Joint Design, Overlaping angle, Ultimate Tensile Strength of Weld Joint.

I. INTRODUCTION

Design of Lap Joint

A lap joint is formed by overlapping two plates and welding them either in the joint where they meet. Lap joints can be used to weld pieces of dissimilar thicknesses and materials. Lap joints also greatly reduce the number of critical parameters in the weld. Unlike a butt weld, which performs a similar function, the lap joint does not require that the cut faces be perfectly flat and parallel. Rather, in a lap joint, the only critical surfaces are the faces of the parts where they overlap, and the tolerances on this overlap are fairly high. The designing of lap joint, care to be taken for lap joint, testing of lap joint and the strength of f lap joint is very important factors

Welded connections involve two components that are both under the direct control of the designer: the joint type, and the weld type. Failures in or near the weld may be the result of an improperly designed joint.

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In this Design File, the principles that should be applied when designing lap joints are presented. A lap joint looks very simple, and it may seem odd that this plain configuration of material would need to be carefully considered. The complication stems from the fact that loads do not instantaneously transfer from one member to another. The three joints in one butt joint, and two lap joints show the differences in the flow of stress through the two joints. The butt joint includes a groove weld while the lap joints use fillet welds. The difference is, stress flow is more associated with the joint type, as opposed to the weld type. The resultant differences in stress distribution result in the need for rules to proportion the lap connection components.

A lap joint and the corresponding welds may seem simple, but a variety of important details need to be considered. The following checklist may be helpful are the parts sufficiently restrained to prevent joint rotation? If not, use at least two rows of welds. Is the overlap at least five times the thickness of the thinner part? And, is it at least 1 in. (25 mm)? For longitudinal welds, are they at least as long as the distance between them? For lap joints with only longitudinal welds, is the distance between the welds less than 8 in. (200 mm)? For cyclically loaded members, is this distance also less than 16 times the thinner member? For material thicknesses of 1/4 in. (6 mm) or more, has the fillet weld leg size been reduced by 1/16 in. (2 mm)?Have the fillet welds been detailed to terminate at least one weld size from the end of the piece? Are they detailed to avoid tying the welds together on opposite sides of the common plane of contact? One final note: these provisions are intended to be applied to lap joints designed to transfer stresses between members. For situations involving lap joints but where the joint is more associated with the assembly of a member, and not with transfer of calculated forces, the principles presented above are not necessarily applicable.[1]

Maximum Weld Size in Lap Joints by The maximum fillet weld size detailed along the edges of base metal in lap joints shall be the following (1) the thickness of the base metal, for metal less than 1/4 in. [6 mm] thick less than the thickness of the base metal, for metal 1/4 in. [6 mm] or more in thickness (see Figure 2.1, Detail B), unless the weld is designated on the shop drawing to be built out to obtain full throat thickness for a leg size equal to the base metal thickness. In the as-welded condition, the distance between the edge of the base metal and the toe of the weld may be less than 1/16 in. [2 mm] provided the weld size is clearly verifiable.[3]

II. PROBLEM STATEMENT

For designing a lap joint there is a reference for overlap of flat plates i.e. from literature reference. But as such no set of standard or reference is there for curved plate regarding the overlap length of joint, which is required for skirt support of pressure vessel. The objective of the project is to form certain set of guidelines or set of formulations which will serve as a guideline for welds of curve plates with an overlap.

III. FINITE ELEMENT ANALYSIS (FEA)

FEA is used in problems where analytical solution not easily obtained Mathematical expressions required for solution not simple because of complex geometries loadings material properties.

Basic FEA Equation

The fundamental FEA equation is this assumption greatly simplifies problem formulation and solution. [F] = [K] * [d]

where:

[F] is the known vector of nodal loads

[K] is the known stiffness matrix

[d] is the unknown vector of nodal displacements

This matrix equation describes the behavior of FEA models. It contains a very large number of linear algebraic equations, varying from several thousand to several million depending on the model size. The stiffness matrix [K] depends on the geometry, material properties, and restraints. Under the linear analysis assumption that the model stiffness never changes, those equations are assembled and solved just once, with no need to update anything while the model is deforming. Thus linear analysis follows a straight path from problem formulation to completion. It produces results in a matter of seconds or minutes, even for very large models.

Principal Steps of Finite element analysis

Pre-processing: The user constructs a model of the part to be analyzed in which the geometry is divided into a number of discrete sub regions, or elements," connected at discrete points called \nodes." Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes vie with one another to have the most user-friendly graphical pre-processor" to assist in this rather tedious chore. Some of these pre-processors can overlay a mesh on a pre existing CAD, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process.

Analysis: The dataset prepared by the pre processor is used as input to the finite element code itself, which constructs and solves a system of linear or nonlinear algebraic equations

Kijuj = fi where u and f are the displacements and externally applied forces at the nodal points. The formation of the K matrix is dependent on the type of problem being attacked, and this module will outline the approach for truss and linear elastic stress analyses. Commercial codes may have very large element libraries, with elements appropriate to a wide range of problem types. One of FEA's principal advantages is that many problem types can be addressed with the same code, merely by specifying the appropriate element types from the library.

Post processing: In the earlier days of finite element analysis, the user would pore through reams of numbers generated by the code, listing displacements and stresses at discrete positions within the model. It is easy to miss important trends and hot spots this way, and modern codes use graphical displays to assist in visualizing the results. A typical postprocessor display overlays colored contours representing stress levels on the model, showing a full field picture similar to that of photo elastic or moiré experimental results. The operation of a specific code is usually detailed in the documentation accompanying the software, and vendors of the more expensive codes will often over workshops or training sessions as well to help users learn the intricacies of code operation. One problem users may have even after this training is that the code tends to be a black box" whose inner workings are not understood. In this module we will outline the principles underlying most current Finite element stress analysis codes, limiting the discussion to linear elastic analysis for now. Understanding this theory helps dissipate the black-box syndrome, and also serves to summarize the analytical foundations of solid mechanics.

IV. ANALYSIS CASES

Analysis for curved plate single side weld:

In this case only single side weld is there and we are analyzing the force required to break the lap joint by changing the overlapping angle. We are taking 30 degree as overlapping angle for first analysis, then increasing the overlapping angle by 5 degree and analyzing the force required to break the lap joint and corresponding deformation. Total no of analysis will be 13.The following are the results for the analysis. i.e force required to break the lap joint and corresponding deformation.

No of Analysis	Overlapping Angle (Degree)	Stress (Mpa)	Force Required to Break the Joint	Corresponding Deformation	No of Elements
1	30	360.85	210	15.283	161204
2	35	359.65	213	14.75	163186
3	40	360.6	217	14.15	164113
4	45	359.57	221.23	13.67	161204
5	50	360.19	225	13.206	168776
6	55	359.47	232	13.1	169104
7	60	360.09	243.2	12.914	169219
8	65	359.68	251.6	12.609	169204
9	70	359.23	265	12.443	173200
10	75	359.4	278	12.574	176021
11	80	360.21	294	12.702	175877
12	85	359.07	296.5	12.901	163452
13	90	359.98	326	13.047	179458

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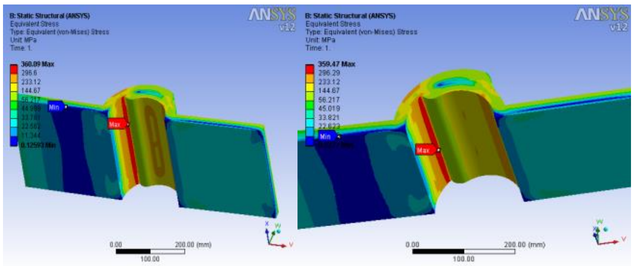
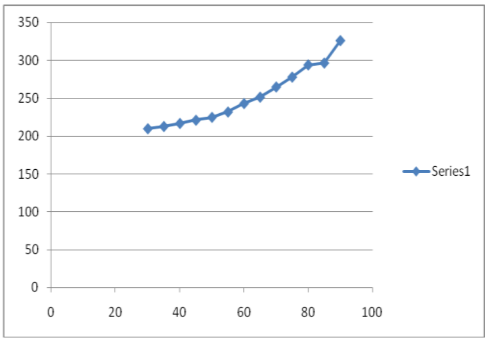


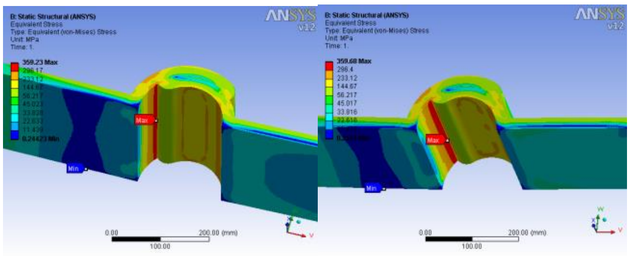


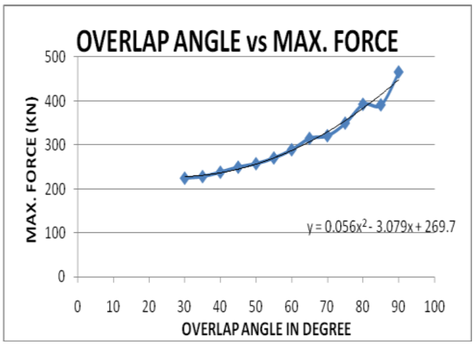
Overlap Angle Vs Force

Analysis for curved plate with both side weld :

In this case only both side weld is there and we are analysing the force required to break the lap joint by changing the overlapping angle. We are taking 30 degree as overlapping angle for first analysis, then increasing the overlapping angle by 5 degree and analysing the force required to break the lap joint and corresponding deformation. Total no of analysis will be 13.The following are the results for the analysis i.e force required to break the lap joint and corresponding deformation.

No of Analysis	Overlapping Angle (Degree)	Stress (Mpa)	Force Required to Break the Joint	Corresponding Deformation	No of Elements
1	30	360.85	225	10.112	156970
2	35	359.65	228.6	9.5111	158320
3	40	360.6	238.5	9.1112	160297
4	45	359.57	250	8.7161	160859
5	50	360.19	257.8	8.1877	160345
6	55	359.47	270.8	7.8232	163313
7	60	360.09	289.6	7.5247	163248
8	65	359.68	315.4	7.3209	168943
9	70	359.23	321.3	6.6462	166169
10	75	359.4	350	6.3878	166887
11	80	360.21	392.7	6.3501	168111
12	85	359.07	391.5	6.3228	168111
13	90	359.98	466	5.8031	171253



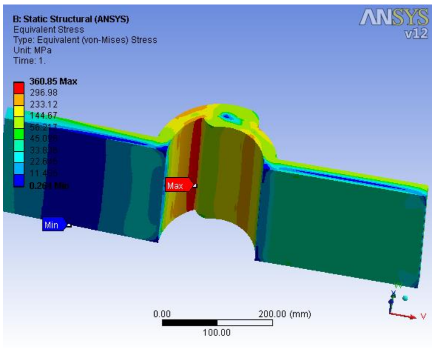


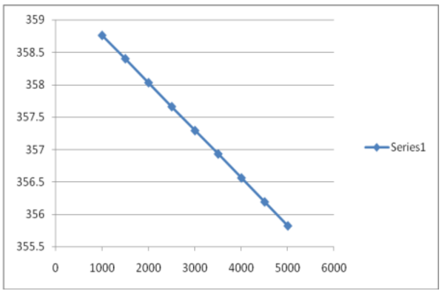
Analysis for curved plate with single side weld & restraining force at other side

In this case only one side weld is there and one side restraining force is applied. We are analyzing the force required to break the lap joint by changing the angle of application of restraining force. We are applying the restraining force at 30,45 and 60 degree. The restraining force is incremented by 500N from 1000N to 5000N. As we are keeping one side weld and applying the restraining force to other side and checking the effect of this on the strength of welded lap joint with its deformation. Total no of analysis will be 09 in each cases.The following are cases to be analysed.

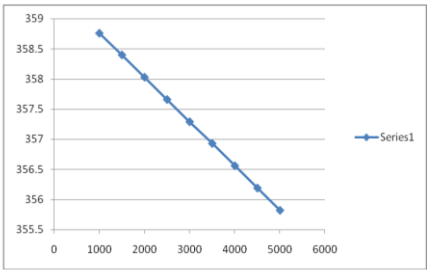
Angle of application of Restraining Force = 45

Sr.No.	Welding(Single Side /Both side)	Force (N)	Stress (N)	Corresponding Deformation
1	Welded lap joint at single side of plate	1000	358.76	14.057
2		1500	358.4	14.193
3		2000	358.03	14.329
4		2500	357.66	14.465
5		3000	357.29	14.601
6		3500	356.93	14.738
7		4000	356.56	14.874
8		4500	356.19	15.011
9		5000	355.82	15.149





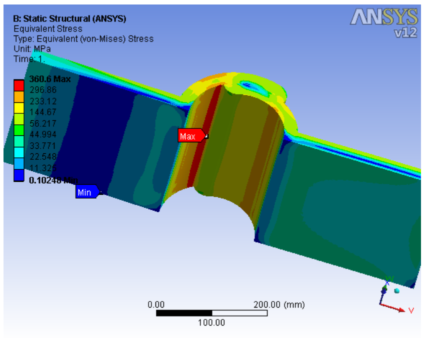
Force Vs Stress

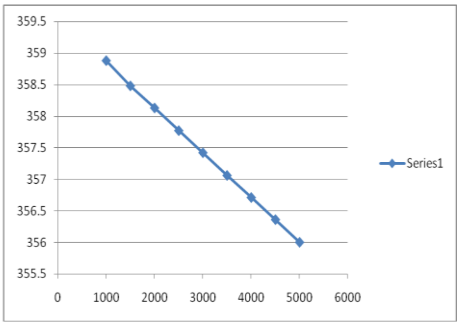


Force Vs Stress

Angle of application of Restraining Force = 60

Sr.No.	Welding(Single Side /Both side)	Force (N)	Stress (N)	Corresponding Deformation
1		**1000**	**358.88**	**13.177**
2		**1500**	**358.48**	**13.321**
3		**2000**	**358.13**	**13.45**
4		**2500**	**357.77**	**13.579**
5	**Welded lap joint at single side of plate**	**3000**	**357.42**	**13.708**
6		**3500**	**357.06**	**13.837**
7		**4000**	**356.71**	**13.961**
8		**4500**	**356.36**	**14.097**
9		**5000**	**356**	**14.226**

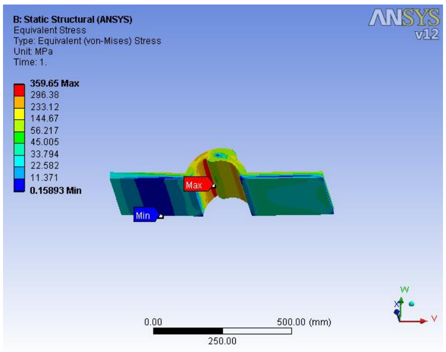




Force Vs Stress

Angle of application of Restraining Force = 90

Sr.No.	Welding(Single Side /Both side)	Force (N)	Stress (N)	Corresponding Deformation
1		1000	373.23	13.257
2		1500	372.83	13.366
3		2000	372.45	13.477
4		2500	372.04	13.586
5	Welded lap joint at single side of plate	3000	371.64	13.696
6		3500	371.23	13.805
7		4000	370.82	13.915
8		4500	370.42	14.025
9		5000	370.02	14.135



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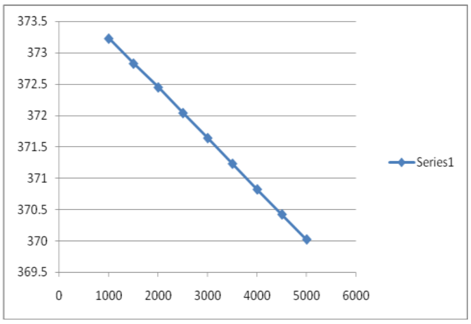

Force Vs Stress

V. ANALYSIS CASES

Experimentation Cases

With the help of Arc Welding machine for welding of specimens as per mentioned below and Universal Testing Machine for testing yield strength, Ultimate tensile strength. The experimentation is divided into three cases, for these three cases 53 tests were conducted.

Experimentation for curved plate single side weld

In this case only single side weld is there and we are finding out with the help of experimentation the force required to break the lap joint by changing the overlapping angle. We are taking 30 degree as overlapping angle for first experimentation, then increasing the overlapping angle by 5 degree and taking results of experimentation i.e. force required to break the lap joint and corresponding deformation. Total no of results by experimentation will be 13.The following are the results of the experimentation conducted.

No of Analysis	Overlapping Angle (Degree)	Stress (Mpa)	Force Required to Break the Joint	Corresponding Deformation
1	30	360.85	199.92	14.52
2	35	359.65	202.78	14.01
3	40	360.6	206.58	13.44
4	45	359.57	210.61	12.99
5	50	360.19	212.63	12.55
6	55	359.47	219.24	12.34
7	60	360.09	229.82	12.16
8	65	359.68	237.76	11.88
9	70	359.23	252.28	11.72
10	75	359.4	261.32	11.76
11	80	360.21	276.36	11.88
12	85	359.07	278.71	12.06
13	90	359.98	306.44	12.20

Experimentation for curved plate with both side weld

In this case thejoint is both side welded and we are experimenting the force required to break the lap joint by changing the overlapping angle. We are taking 30 degree as overlapping angle for first experimentation, then increasing the overlapping angle by 5 degree and taking results i.e. the force required to break the lap joint and corresponding deformation. Total no of experiments will be 13.The following are the results of the experimentation i.e. force required to break the lap joint and corresponding deformation.

No of Analysis	Overlapping Angle(Degree)	Stress (Mpa)	Force Required to Break the Joint	Corresponding Deformation
1	30	360.85	211.05	9.53
2	35	359.65	214.43	8.96
3	40	360.6	223.71	8.58
4	45	359.57	234.50	8.21
5	50	360.19	241.82	7.64
6	55	359.47	256.18	7.30
7	60	360.09	273.96	7.02
8	65	359.68	298.37	6.83
9	70	359.23	300.42	6.20
10	75	359.4	327.25	5.97
11	80	360.21	367.17	5.93
12	85	359.07	366.05	5.91
13	90	359.98	435.71	5.42

Experimentation for curved plate with single side weld & restraining force at other side

In this case only one side weld is there and one side restraining force is applied. We are experimenting the force required to break the lap joint by changing the angle of application of restraining force. We are applying the restraining force at 30,45 and 60 degree. The restraining force is incremented by 500N from 1000N to 5000N. As we are keeping one side weld and applying the restraining force to other side and taking the results for the strength of welded lap joint with its deformation. Total no of results will be 10 in each cases and following are results of this experimentation.

Angle of application of Restraining Force = 45

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Sr.No.	Welding(Single Side /Both side)	Force (N)	Stress (Mpa)	Corresponding Deformation
1		1000	338.31	12.83
2		1500	337.97	12.96
3		2000	337.62	13.08
4		2500	333.34	13.84
5	Welded lap joint at single side of plate	3000	332.99	13.97
6		3500	332.66	14.10
7		4000	332.31	13.61
8		4500	331.26	13.74
9		5000	330.91	13.86

Angle of application of Restraining Force = 60

Sr.No.	Welding(Single Side /Both side)	Force (N)	Stress (Mpa)	Corresponding Deformation
1		1000	326.94	12.00
2		1500	326.58	12.14
3		2000	326.26	12.25
4		2500	325.93	12.37
5	Welded lap joint at single side of plate	3000	160.84	12.49
6		3500	160.68	12.61
7		4000	160.52	12.72
8		4500	160.36	12.84
9		5000	160.20	12.96

Angle of application of Restraining Force = 90

Sr.No.	Welding(Single Side /Both side)	Force (N)	Stress(N)	Corresponding Deformation
1		1000	347.48	12.53
2		1500	347.10	12.63
3		2000	346.75	12.74
4		2500	346.37	12.84
5	Welded lap joint at single side of plate	3000	346.00	12.94
6		3500	345.62	13.05
7		4000	345.23	13.15
8		4500	344.86	13.25
9		5000	344.49	13.36

VI. RESULTS AND DISCUSSION

Cases of Results and Experimentation

We have conducted total 53 analyses and experimentation for the analysis of curved plate lap joint regarding overlap length. Analysis results and experimentation results will be discussed according to the following three cases.

1. Analysis for curved plate single side weld
2. Analysis for curved plate with both side weld
3. Analysis for curved plate with single side weld & Restraining force at other side
   a) Angle of application of Restraining Force = 45
   b) Angle of application of Restraining Force = 60
   c) Angle of application of Restraining Force = 90

In first case i.e welding to single side and incrementing the overlapping angle by 5 degree the force required to break the joint is analyzed. In second case the welding is at both side and again incrementing the overlapping angle by 5 the force required to break the joint. In third case one side is welded and at another side restraining force is applied, In this case again the angle of application of restraining force is 30,60 and 90 degree. We have completed total 53 analyses for above mentioned all cases.

Same cases are experimented the results of this experimentation is given in previous chapter. validation.

6.2 Analysis Results and Discussion

In first case as the overlapping angle is increased there is increase in strength of weld joint. Strength of weld joint is increasing linearly with increase in overlapping angle. As the overlapping angle is increased the deformation is decreasing i.e. increase in overlapping angle lead to decrease in deformation.

In second case also as the overlapping angle is increased there is increase in strength of weld joint. Strength of weld joint is increasing linearly with increase in overlapping angle. As the overlapping angle is increased the deformation is decreasing i.e. increase in overlapping angle lead to decrease in deformation.

In third cases application of restraining force angle of application is 30,60 and 90 degrees. As the force is increased the strength is increased but it is not considerable it is negligible i.e. the effect of one side weld with other side application of restraining force even though increasing the restraining force the effect on strength of weld joint is not considerable it is negligible. This effect is same for the deformation also due to application of restraining force there is certain change in deformation of weld joint but still it is not considerable. The analysis results for strength of weld joint and corresponding deformation is same in three cases i.e angle of application of restraining force is 30,60 and 90.

Experimentation Results and Discussion

In both the first and second case as the overlapping angle is increased there is linear increase in strength of weld joint and linear decrease in corresponding deformation. In third case strength is increased and deformation is decreased but change in both this parameters is not considerable it is negligible in three sub cases of angle of application of restraining force.

We can summarize that the experimentation results for above mentioned three cases i.e. 53 analyses are same the difference between analysis result and experimentation results is near about from 3.1% to 5.3%.

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VII CONCLUSION

We have divided this project in three different cases i.e one side weld,both side weld and one side weld with application of restraining force at other side. We have already mentioned in previous chapter that the experimentation results for above mentioned three cases i.e. 53 analyses are same the difference between analysis result and experimentation results is near about from 3.1% to 5.3%.

In first case i.e. single side weld as the increase in overlapping angle there is increase in strength of weld joint and decrease in corresponding deformation. It is same as compared to both side weld till 50 degree overlapping angle but after 50 degree the benefit is less as compared to both side weld.

In second case there is linear increase in strength of weld joint and decrease in corresponding deformation. As per the analysis and experimentation results the strength is same and so the corresponding deformation. But the benefit i.e. strength of weld joint and corresponding deformation after the overlapping angle of 50 degree is more as compared to the single side weld and single side weld with restraining force at other side. So it is better to use both side weld if the overlapping angle is above 50 degree.

In third case the welding is at one side and restraining force at other side but as such there is no any considerable effect on strength of weld joint and corresponding deformation. i.e. the effect of application of restraining force in curved plate weld analysis is negligible.

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