Journal of Welding Technology
P-ISSN: 2716-1471 | E-ISSN: 2716-0475
http://e-jurnal.pnl.ac.id/Welding_Technology

Comparative finite element analysis of IIW linear stress extrapolation and haibach methods for structural hot-spot stress prediction in welded plate joints

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Article Processing Dates:
Received 2026-05-23
Accepted 2026-06-27
Available online 2026-06-30

Keywords:
Structural hot-spot stress
Welded joints
Finite element analysis
IIW Linear Stress Extrapolation
Haibach method

Abstract

Accurate prediction of structural hot-spot stress (SHSS) is essential for evaluating welded joints. This study compares the International Institute of Welding (IIW) Linear Stress Extrapolation (LSE) and Haibach methods using finite element analysis performed with the open-source software CalculiX. Three weld geometry representations (no weld, chamfer, and fillet) and two mesh densities (fine and coarse) were investigated, resulting in six finite element models. Both SHSS methods were applied to evaluate stress prediction, mesh sensitivity, weld geometry effects, and computational performance. The IIW LSE method consistently predicted higher SHSS than the Haibach method, while mesh refinement produced variations below 4%. In contrast, weld geometry had a greater influence on SHSS prediction, with the chamfer model producing the highest stress. Fine meshes required approximately five to six times longer computational time than coarse meshes while providing only marginal improvements in SHSS prediction. Weld geometry representation was therefore found to have a greater influence on SHSS prediction than mesh density. The IIW LSE method is recommended for conservative structural assessment, whereas the Haibach method is suitable for preliminary engineering analyses requiring simpler post-processing.

1. Introduction

Welded joints are widely employed in engineering structures such as pressure vessels, pipelines, bridges, and offshore systems, where the stress distribution around the weld toe plays a critical role in structural performance. The geometric discontinuity created by the weld profile produces localized stress concentrations under external loading, making the weld toe the most critical region for stress evaluation. Therefore, accurate prediction of the maximum principal stress at the weld toe is essential for structural integrity assessment, finite element-based design verification, and the evaluation of welded joint performance [1], [2], [3], [4], [5].

The structural hot-spot stress (SHSS) method is widely used to evaluate structural stress concentrations at welded joints while excluding localized notch stresses caused by the weld profile. SHSS provides more representative stress predictions near the weld toe without the extensive mesh refinement required for notch stress analysis and is well suited for finite element analysis (FEA).

The International Institute of Welding (IIW) recommends the surface stress extrapolation method, in which structural hot-spot stress is obtained by extrapolating stresses from predefined reference locations toward the weld toe. IIW method for hot-spot stress can be seen in Figure 1 [6].

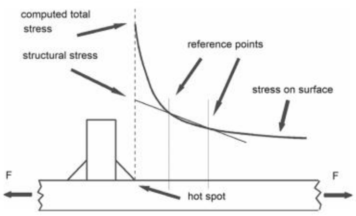


Fig. 1. IIW definition of structural hot-spot stress

For nonlinear stress distributions, the IIW Linear Stress Extrapolation (LSE) method determines structural hot-spot stress using two reference points. Depending on the hot-spot type, the reference-point locations are defined either as normalized distances based on plate thickness (Type a) or as fixed absolute distances independent of plate thickness (Type b). The reference-point configurations for both hot-spot types are shown in Figure 2 [6], [7], [8], [9], [10] .

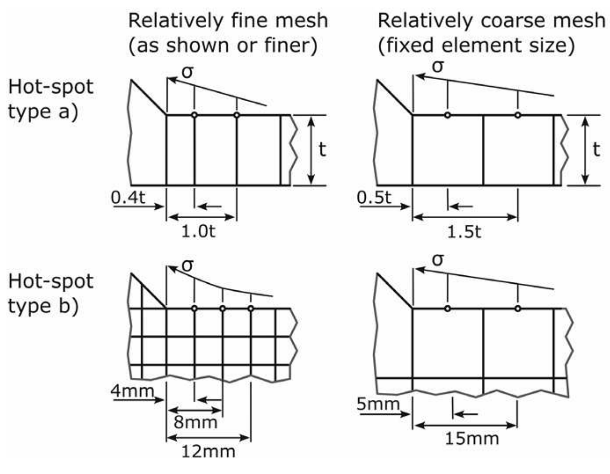


Fig. 2. IIW two hot-spot reference point

In contrast, the Haibach method determines structural stress from a single stress value measured at a fixed distance of approximately 2.0 - 2.5 mm from the weld toe. Because of its single-point formulation, the Haibach method is computationally simpler to implement in finite element post-processing, although its predictions may be more sensitive to local mesh refinement and geometric representation. Haibach method for hot-spot stress can be seen in Figure 3 [10].

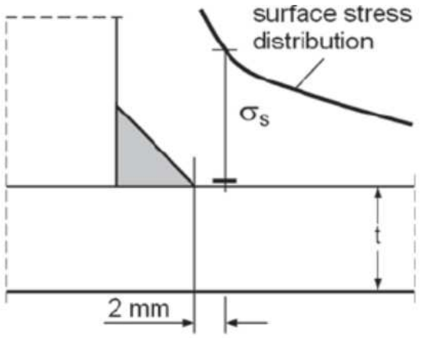


Fig. 3. Haibach hot-spot reference point

In finite element modeling, the weld toe can be represented using different geometric idealizations, such as a fillet, a chamfer, or a sharp transition without explicit weld geometry. These modeling approaches produce different stress distributions near the weld toe and may affect both the predicted structural hot-spot stress and the computational effort required for analysis. Although these geometric representations are widely used in engineering practice, their influence on different SHSS evaluation methods has not been systematically investigated. The weld toe geometric detail difference for sharp transition and chamfer model can be seen in Figure 4 [6], [7].

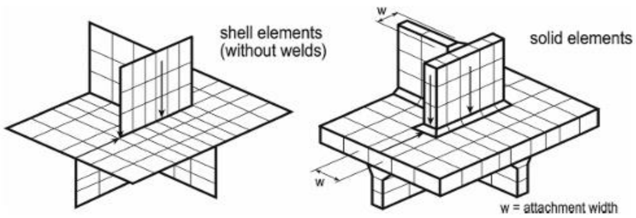


Fig. 4. Comparison of weld representations

Previous studies have demonstrated that finite element modeling parameters significantly influence SHSS predictions. Iqbal et al [9] compared several structural hot-spot stress methods for welded orthotropic steel deck joints and reported that the IIW extrapolation method generally produced more consistent stress predictions than single-point evaluation techniques under different meshing strategies. Similarly, Marchetta et al [3] highlighted the importance of mesh convergence for reliable hot-spot stress prediction in laser-welded Ti6Al4V joints. Other studies have shown that weld geometry also plays a significant role in stress evaluation. Mert [11] demonstrated that variations in weld toe geometry substantially affect stress concentration and fatigue behavior, while Remes et al [10] reported that simplified and realistic weld geometry models can produce different structural stress predictions, particularly for thin-walled welded joints. Nevertheless, these studies primarily focused on fatigue assessment or specific weld geometry characteristics rather than systematically comparing SHSS evaluation methods. Moreover, the combined effects of mesh density, practical weld geometry representations (fillet, chamfer, and no explicit weld geometry), and computational efficiency on maximum principal stress prediction remain insufficiently investigated, particularly for simple welded plate joints [12].

Unlike previous studies that primarily focused on either mesh convergence, weld geometry effects, or SHSS evaluation techniques in isolation, this study provides a systematic and controlled comparison of the IIW Linear Stress Extrapolation (LSE) and Haibach methods using identical finite element models with varying weld geometry representations and mesh densities. The influence of weld geometry, mesh refinement, and computational efficiency on SHSS prediction is simultaneously evaluated to establish the relative performance and applicability of each method. The IIW LSE and Haibach methods were selected because they represent two widely adopted SHSS evaluation approaches with fundamentally different stress evaluation principles: the IIW LSE method employs multi-point stress extrapolation, whereas the Haibach method relies on single-point stress evaluation. Comparing these methods under identical modeling conditions provides practical guidance for selecting an appropriate SHSS evaluation procedure for engineering design and structural integrity assessment.

2. Research Methods

A comparative finite element analysis (FEA) was conducted using the open-source finite element software CalculiX to evaluate the performance of the IIW Linear Stress Extrapolation (LSE) and Haibach structural hot-spot stress (SHSS) methods under different modeling conditions. The study considered three weld geometry representations (no weld, chamfer, and fillet) and two mesh densities (fine and coarse), resulting in six finite element models. Each model was subsequently evaluated using both SHSS methods, yielding twelve SHSS evaluations. The comparison was based on maximum principal stress prediction, mesh sensitivity, weld geometry representation, and computational efficiency.

2.1. Weld geometry, properties, and conditions

A three-dimensional welded plate joint was modeled using solid finite elements. The base plate had dimensions of 87 mm × 150 mm × 8 mm, while the weld leg size was 4 mm. S185 structural steel was assigned to all models, which were created as a single compound solid body. The model can be seen in Figure 5. The welded joint geometry represents a simplified pipe support connection, where the welded plate transfers the load from the supported pipe to the supporting structure. The applied loading condition was selected to represent the combined weight of the pipe, the contained fluid, and the thermal insulation acting on the support.

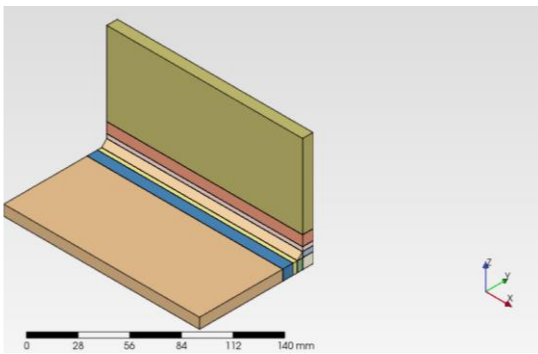


Fig. 5. Welded joint model

Three weld geometry representations were investigated to evaluate the influence of weld toe idealization on structural hot-spot stress prediction.

The first configuration was a no-weld model, in which the joint was represented by a sharp plate transition without explicit weld geometry. The model can be seen in Figure 6.

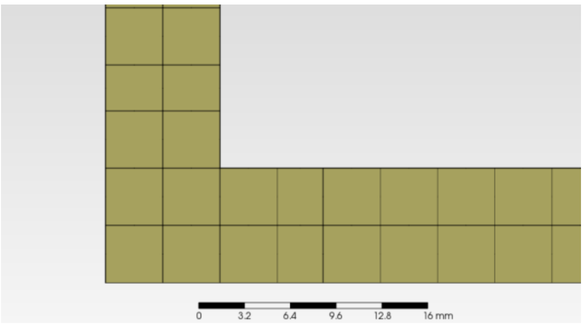


Fig. 6. No-weld joint model

The second configuration employed a 4 mm chamfer weld, representing an angular weld profile at the weld toe. The model can be seen in Figure 7.

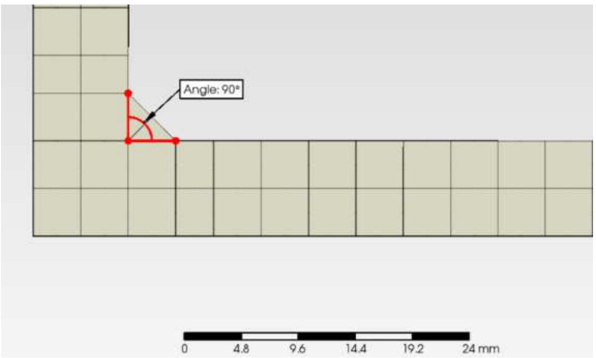


Fig. 7. Chamfer joint model

The third configuration used a fillet weld with a 4 mm weld leg, representing a smooth curved weld profile. The corresponding fillet radius were calculated using Eq (1) [7].

$$r = w_s \times \sqrt{2} \qquad (1)$$

where r is the fillet radius (mm) and w_s is the weld leg size (mm)

The model for fillet weld can be seen in Figure 8.

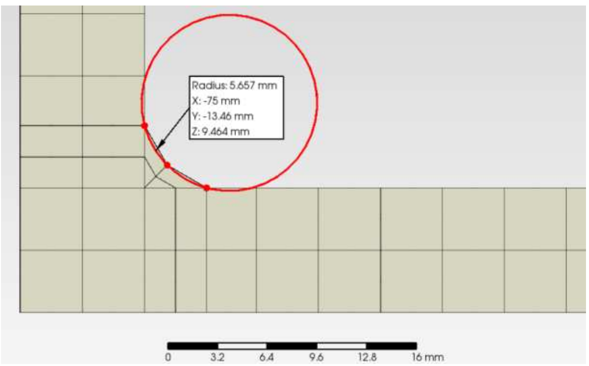


Fig. 8. Fillet joint model

A rigid body constraint was applied at one end of the specimen to simulate a fully fixed support. A static concentrated load of 300 N was applied at the opposite end in a single static analysis step.

The selected load of 300 N represents a representative service load corresponding to the combined weight of the supported pipe, the contained fluid, and the thermal insulation acting on the pipe support, thereby providing a representative service loading condition for evaluating the structural hot-spot stress (SHSS) methods. This loading configuration generated a stress gradient along the plate, producing the maximum principal stress at the weld toe, which served as the evaluation location for both SHSS methods.

2.2. Weld mesh configuration

Two mesh densities were employed to investigate the impact of mesh density on structural hot-spot stress (SHSS) prediction. The finite element meshes were generated using the open-source finite element software CalculiX with a structured transfinite meshing technique to produce a regular and consistent element distribution throughout the welded joint models. The transfinite meshing approach ensured that corresponding edges contained the same number of divisions, resulting in a structured mesh with minimal element distortion and uniform element quality. This strategy allowed differences in the predicted SHSS to be attributed primarily to mesh density rather than irregular element distribution or poor mesh quality.

The fine mesh employed a maximum element size of 4 mm with a minimum element size of 0 mm, whereas the coarse mesh used a maximum element size of 8 mm with a minimum element size of 2 mm. Both mesh configurations were generated using the same transfinite meshing strategy to ensure consistency between the models. The fine mesh contained approximately 18,000 to 21,000 nodes and 3,200 to 3,700 solid elements, whereas the coarse mesh consisted of approximately 3,500 to 4,200 nodes and 475 to 594 elements.

The structured transfinite mesh improves element quality, promotes reliable mesh convergence, and provides a stable representation of the stress gradient around the weld toe. Consequently, any differences in SHSS prediction between the fine and coarse meshes can be attributed primarily to mesh density rather than numerical errors associated with distorted or irregular finite elements.

2.3. Structural hot-spot stress evaluation

The structural hot-spot stress (SHSS) of each model was evaluated using the IIW Linear Stress Extrapolation (LSE) and Haibach methods, two widely adopted procedures for assessing structural stresses in welded joints. Both methods were applied to the same finite element results to ensure a consistent basis for comparison.

The IIW LSE method determines SHSS through linear extrapolation of the maximum principal stress obtained at multiple reference locations positioned at prescribed distances from the weld toe in accordance with IIW recommendations. In contrast, the Haibach method determines SHSS directly from the maximum principal stress measured at a single reference point located near the weld toe without requiring stress extrapolation. By applying both methods to identical finite element models, the influence of mesh density and weld geometry representation on SHSS prediction could be systematically evaluated while highlighting the differences in stress prediction, implementation complexity, and engineering applicability between the two approaches.

2.3.1 IIW LSE method

For fine mesh, structural hot-spot stress was evaluated using the IIW surface stress extrapolation procedure. For the fine mesh, the IIW Linear Stress Extrapolation (LSE) method was applied using two reference points located at 0.4t (3.2 mm) and 1.0t (8.0 mm) from the weld toe, as recommended by the IIW guideline. The reference point can be seen in Figure 9.

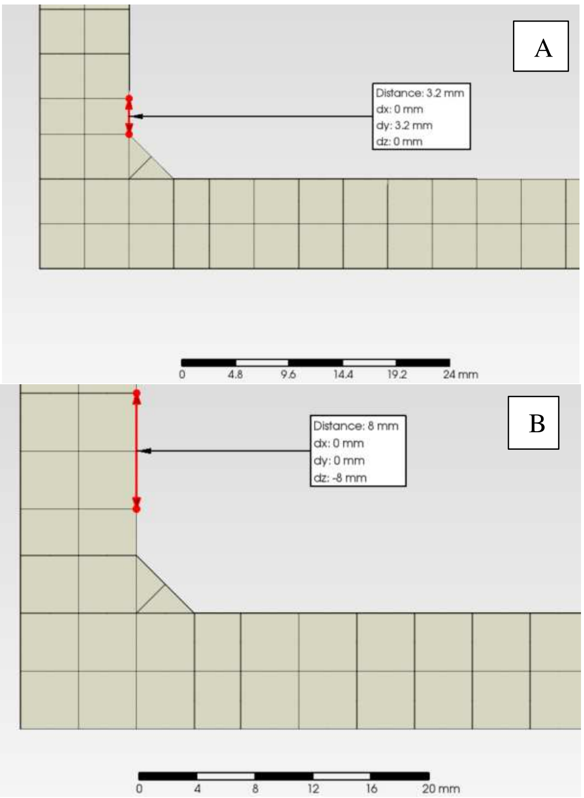


Fig. 9. Reference point; (A) 0.4t, (B) 1.0t

The IIW structural hot-spot stress for fine mesh were calculated using Eq (2) [6], [10], [12].

$$\sigma_{hs} = 1.67\sigma_{0.4t} - 0.67\sigma_{1.0t} \quad (2)$$

where σ_{hs} is the structural hot-spot stress (MPa) and $\sigma_{0.4t}$ and $\sigma_{1.0t}$ are the maximum principal stresses (MPa) measured at distances of 0.4t and 1.0t from the weld toe, respectively.

For the coarse mesh, the IIW Linear Stress Extrapolation (LSE) method was applied using two reference points located at 0.5t (4.0 mm) and 1.5t (12.0 mm) from the weld toe, as recommended by the IIW guideline. The reference point can be seen in Figure 10.

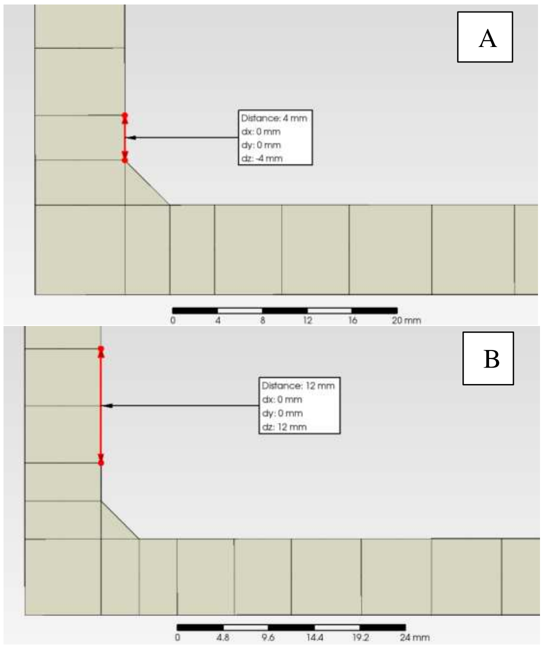


Fig. 10. Reference point; (A) 0.5t, (B) 1.5t

The IIW structural hot-spot stress (SHSS) for coarse mesh were calculated using Eq (3) [6], [10], [12].

$$\sigma_{hs} = 1.5\sigma_{0.5t} - 0.5\sigma_{1.5t} \quad (3)$$

where σ_{hs} is the structural hot-spot stress (MPa) and $\sigma_{0.5t}$ and $\sigma_{1.5t}$ are the maximum principal stresses (MPa) measured at distances of 0.5t and 1.5t from the weld toe, respectively.

2.3.2 Haibach method

The Haibach method determines the structural hot-spot stress directly from the maximum principal stress measured at a single reference point located 2.0 to 2.5 mm from the weld toe.

In the present study, a reference distance of 2.5 mm was adopted, and the measured maximum principal stress at this location was taken directly as the structural hot-spot stress (SHSS) without stress extrapolation. The reference point can be seen in Figure 11 [10].

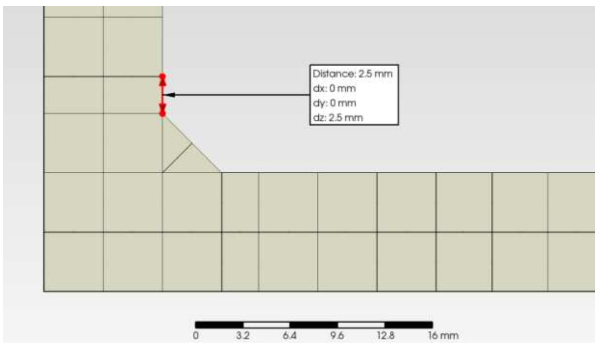


Fig. 11. Reference point 2.5 mm

2.4. Evaluation criteria

The IIW Linear Stress Extrapolation (LSE) and Haibach methods were evaluated using four performance criteria. First, the maximum principal stress prediction was compared to assess the structural hot-spot stress obtained by each method under identical loading conditions. Second, mesh sensitivity was evaluated by comparing the stress predictions obtained from fine and coarse mesh models. Third, the influence of weld geometry representation was investigated by analyzing the stress predictions for the no-weld, chamfer, and fillet configurations. Finally, computational efficiency was assessed using the total FEA computation time, defined as the sum of mesh generation time and solver elapsed time for each model.

The results obtained from these evaluations were used to compare the performance of the IIW LSE and Haibach methods and to identify their respective advantages, limitations, and suitable applications based on stress prediction capability, sensitivity to mesh density and weld geometry, and computational efficiency.

3. Results and Discussion.

3.1 Structural hot-spot stress prediction

For the IIW method, the fine mesh employed the Type a linear extrapolation procedure using reference points at 0.4t and 1.0t, whereas the coarse mesh used reference points at 0.5t and 1.5t in accordance with the IIW recommendations. The Haibach method evaluated structural hot-spot stress (SHSS) directly from the maximum principal stress at a single reference point located 2.5 mm from the weld toe. Table 1 summarizes the SHSS obtained using the IIW Linear Stress Extrapolation (LSE) and Haibach methods for all finite element models.

Table 1. Structural hot-spot stress (SHSS) for all models

Method	Mesh	Weld Geometry	SHSS (MPa)
IIW LSE	Fine	No weld	11.94
IIW LSE	Fine	Chamfer	13.90
IIW LSE	Fine	Fillet	13.42
IIW LSE	Coarse	No weld	12.16
IIW LSE	Coarse	Chamfer	13.40
IIW LSE	Coarse	Fillet	13.58
Haibach	Fine	No weld	10.99
Haibach	Fine	Chamfer	12.81
Haibach	Fine	Fillet	12.38
Haibach	Coarse	No weld	11.25
Haibach	Coarse	Chamfer	12.53
Haibach	Coarse	Fillet	12.38

The difference between the IIW LSE and Haibach methods ranged from approximately 0.90 MPa to 1.09 MPa, with the IIW method consistently producing higher SHSS values.

Overall, both methods exhibited similar responses to changes in mesh density and weld geometry. Introducing explicit weld geometry increased the predicted SHSS relative to the no-weld model, whereas mesh refinement produced comparatively small changes in the calculated stress. However, the IIW method consistently predicted higher SHSS values than the Haibach method for every modeling configuration.

Figure 12 shows the maximum principal stress contour for the chamfered weld model together with the reference locations used by the IIW LSE and Haibach methods for structural hot-spot stress evaluation.

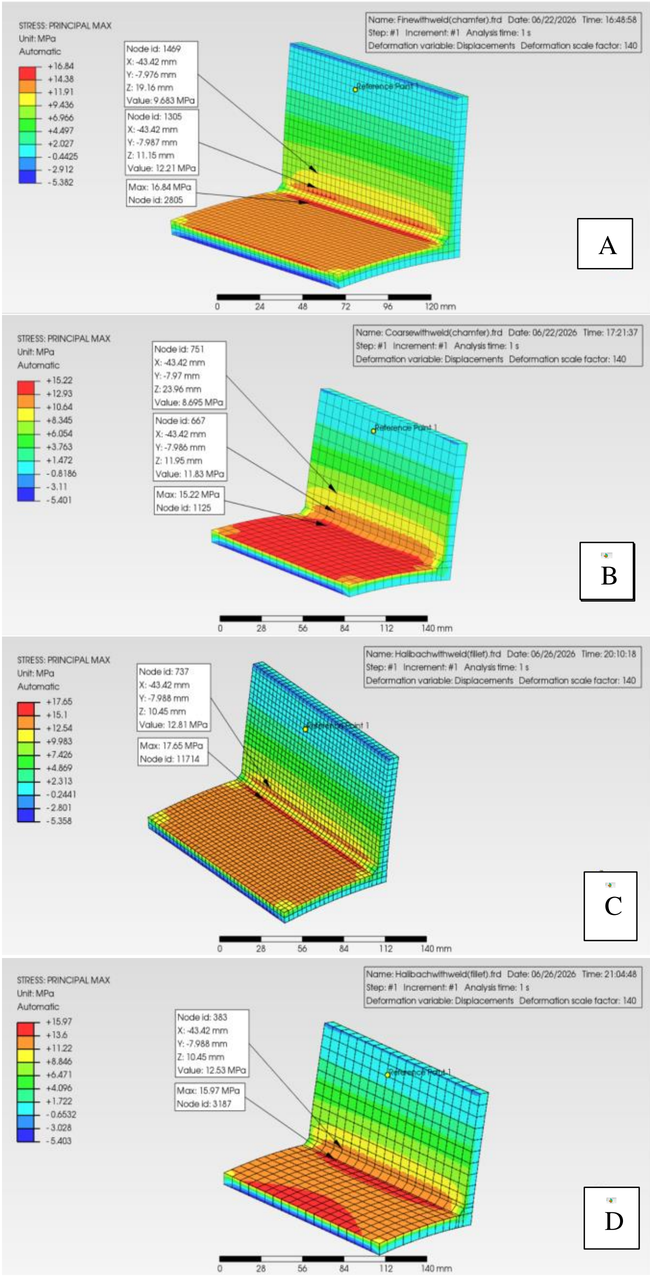


Fig. 12. Chamfer contour result based on method and mesh; (A) IIW LSE Fine, (B) IIW LSE Coarse (C) Haibach Fine, (D) Haibach Coarse

Figure 13 shows the maximum principal stress contour for the fillet weld model together with the reference locations used by the IIW LSE and Haibach methods for structural hot-spot stress evaluation.

Figure 14 shows the maximum principal stress contour for the no-weld model together with the reference locations used by the IIW LSE and Haibach methods for structural hot-spot stress evaluation.

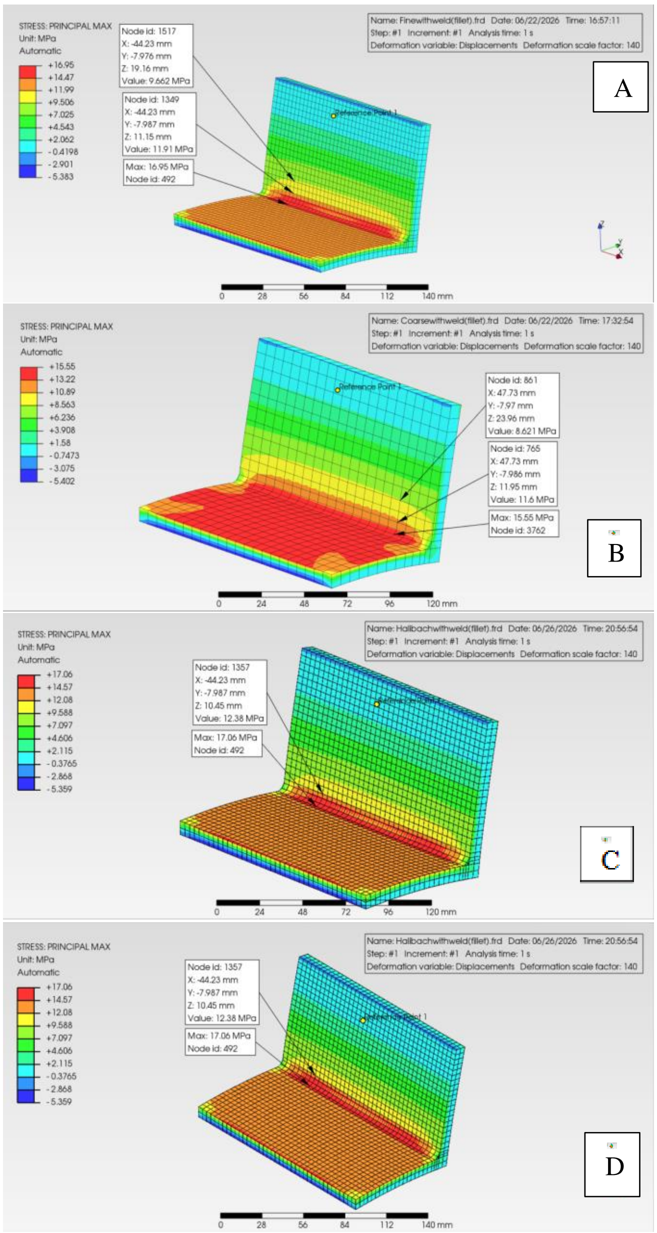
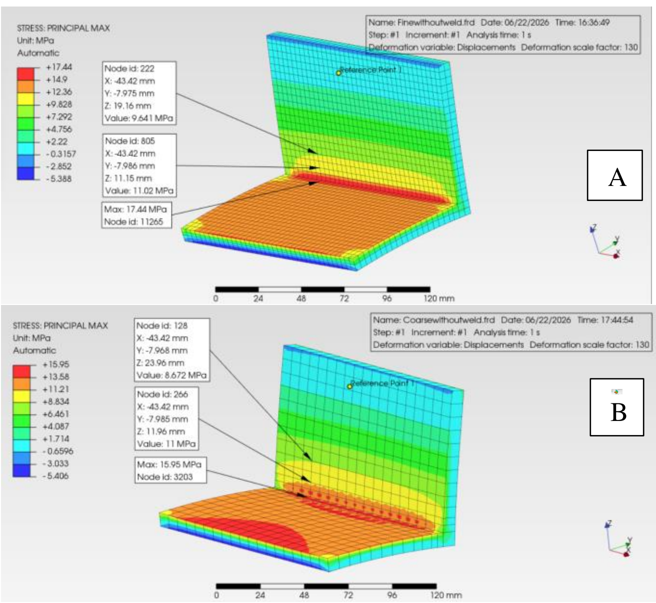


Fig. 13. Fillet contour result based on method and mesh; (A) IIW LSE Fine, (B) IIW LSE Coarse (C) Haibach Fine, (D) Haibach Coarse



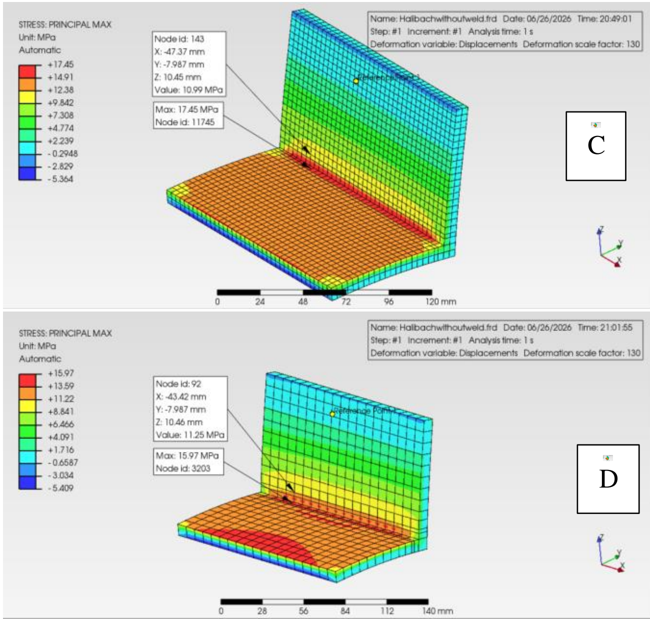


Fig. 14. No-weld contour result based on method and mesh; (A) IIW LSE Fine, (B) IIW LSE Coarse (C) Haibach Fine, (D) Haibach Coarse

For the fine mesh models, the IIW method predicted SHSS values between 11.94 MPa and 13.90 MPa, whereas the Haibach method predicted 10.99 to 12.81 MPa. Similarly, for the coarse mesh models, the IIW method produced SHSS values of 12.16 to 13.58 MPa, compared with 11.25 to 12.53 MPa for the Haibach method. The highest SHSS obtained in this study was 13.90 MPa for the fine chamfer model evaluated using the IIW method, while the lowest value was 10.99 MPa for the fine no-weld model evaluated using the Haibach method.

Despite these differences in magnitude, all models exhibited similar maximum principal stress contour distributions, with the highest stresses consistently concentrated at the weld toe or joint transition region. The contour plots for the no-weld, chamfer, and fillet models show that both the IIW LSE and Haibach methods identify the same critical stress location, although the IIW method generally predicts higher structural hot-spot stress values due to its stress extrapolation procedure.

The consistently higher SHSS predicted by the IIW method can be attributed to its stress extrapolation procedure, which estimates the structural stress at the weld toe using stresses obtained from multiple reference locations. In contrast, the Haibach method directly adopts the stress measured at a single point 2.5 mm from the weld toe. Because the IIW method accounts for the stress gradient approaching the weld toe, it generally provides a more conservative estimate of SHSS.

These findings agree with those reported by Iqbal et al. [9], who observed that IIW extrapolation methods produced more consistent structural hot-spot stress predictions than single-point evaluation techniques under different meshing strategies. Although their study considered fatigue behavior in orthotropic steel deck joints, the present results demonstrate that the same trend is maintained for a simple welded plate subjected to static loading. This suggests that the robustness of the IIW extrapolation procedure is not restricted to a specific structural configuration.

3.2 Influence of mesh density

The influence of mesh density on SHSS prediction was relatively small for both evaluation methods. Increasing the mesh density from approximately 3,500 to 4,200 nodes and 475 to 594 elements to 18,000 to 21,000 nodes and 3,200 to 3,700 elements produced only minor changes in the calculated SHSS. The mesh characteristics of all finite element models are summarized in Table 2.

Table 2. Mesh characteristics

Method	Mesh	Weld Geometry	Nodes	Elements
IIW LSE	Fine	No weld	18,201	3,192
IIW LSE	Fine	Chamfer	18,395	3,268
IIW LSE	Fine	Fillet	19,943	3,588
IIW LSE	Coarse	No weld	3,548	475
IIW LSE	Coarse	Chamfer	3,568	494
IIW LSE	Coarse	Fillet	4,202	594
Haibach	Fine	No weld	19,053	3,344
Haibach	Fine	Chamfer	19,247	3,42
Haibach	Fine	Fillet	20,817	3,744
Haibach	Coarse	No weld	3,548	475
Haibach	Coarse	Chamfer	3,568	494
Haibach	Coarse	Fillet	4,202	594

The effect of mesh density on the predicted SHSS is presented in Table 3.

Table 3. Mesh density on SHSS

Method	Weld Geometry	Fine (MPa)	Coarse (MPa)	Difference (%)
IIW LSE	No weld	11.94	12.16	1.84
IIW LSE	Chamfer	13.90	13.40	3.64
IIW LSE	Fillet	13.42	13.58	1.20
Haibach	No weld	10.99	11.25	2.37
Haibach	Chamfer	12.81	12.53	2.19
Haibach	Fillet	12.38	12.38	0.00

For the IIW LSE method, the difference between the fine and coarse meshes ranged from 1.20% to 3.64%, whereas the Haibach method exhibited differences between 0.00% and 2.37%, depending on the weld geometry. These relatively small variations indicate that both mesh configurations achieved mesh-converged SHSS predictions for the investigated welded plate joint.

The low mesh sensitivity is attributed to the structured transfinite meshing strategy adopted in this study. The transfinite mesh generated a regular element distribution with controlled element sizes, thereby minimizing numerical errors associated with irregular or distorted elements and enabling consistent stress evaluation near the weld toe. As a result, both mesh densities produced stable and converged SHSS predictions.

Although the fine mesh provided higher spatial resolution of the stress gradient near the weld toe, the improvement in SHSS prediction was relatively small compared with the substantial increase in model size. This observation agrees with the findings of Marchetta et al [3], who emphasized that mesh convergence is essential for reliable SHSS prediction. However, unlike their fatigue-oriented investigation of laser-welded Ti6Al4V joints, the present study demonstrates that, once a structured and converged mesh is established, further mesh refinement yields only marginal improvements in SHSS prediction while significantly increasing computational cost for simple welded plate models.

3.3 Influence of weld geometry representation

Weld geometry representation had a more pronounced influence on structural hot-spot stress (SHSS) prediction than mesh density. Explicit representation of the weld geometry produced higher SHSS than the corresponding no-weld models for both evaluation methods. The SHSS values obtained for each weld geometry are summarized in Table 4.

Table 4. Weld geometry on SHSS

Method	Mesh	No Weld (MPa)	Chamfer (MPa)	Fillet (MPa)
IIW LSE	Fine	11.94	13.90	13.42
IIW LSE	Coarse	12.16	13.40	13.58
Haibach	Fine	10.99	12.81	12.38
Haibach	Coarse	11.25	12.53	12.38

For the fine mesh models, the chamfer weld produced the highest SHSS, reaching 13.90 MPa using the IIW LSE method and 12.81 MPa using the Haibach method. The fillet weld produced slightly lower SHSS values of 13.42 MPa and 12.38 MPa, respectively. A similar trend was observed for the coarse mesh models, where both chamfer and fillet welds produced higher SHSS than the no-weld configuration.

The results indicate that weld geometry representation has a greater influence on SHSS prediction than mesh density. Introducing an explicit weld profile increased the predicted structural stress because the weld toe geometry altered the local stress concentration compared with the simplified no-weld model. The slightly higher SHSS obtained for the chamfer model under the fine mesh suggests that the sharper weld toe transition generated a steeper stress gradient than the smoother fillet profile.

The difference between the chamfer and fillet models became smaller for the coarse mesh, indicating that reduced mesh resolution is less capable of capturing localized stress gradients around the weld toe. Consequently, although coarse meshes provide satisfactory overall SHSS predictions, they may underestimate the influence of weld geometry details.

These observations are consistent with the findings of Mert [11], who reported that weld toe geometry significantly affects stress concentration and fatigue behavior. Likewise, Remes et al [10] showed that simplified and realistic weld geometry models can produce different structural stress predictions, particularly for thin-walled welded joints. Although the present study focuses on structural hot-spot stress rather than fatigue life, the results confirm that explicit weld geometry should be incorporated into finite element models to obtain reliable SHSS predictions.

3.4 Computational performance

The total computational time for all finite element models is summarized in Table 5. Fine mesh models required total processing times ranging from 8.68 s to 12.57 s, whereas coarse mesh models required only 1.77 s to 2.09 s, corresponding to an approximately five- to six-fold reduction in computational time.

Table 5. Total computational time for all models

Method	Mesh	Weld Geometry	Total Time (s)
IIW LSE	Fine	No weld	8.678
IIW LSE	Fine	Chamfer	9.050
IIW LSE	Fine	Fillet	10.151
IIW LSE	Coarse	No weld	1.812
IIW LSE	Coarse	Chamfer	1.832
IIW LSE	Coarse	Fillet	2.041
Haibach	Fine	No weld	10.340
Haibach	Fine	Chamfer	10.406
Haibach	Fine	Fillet	12.566
Haibach	Coarse	No weld	1.767
Haibach	Coarse	Chamfer	1.800
Haibach	Coarse	Fillet	2.087

The increase in computational time is primarily attributed to the larger number of nodes and elements in the fine mesh models, which increased both mesh generation and solver time. The slightly longer processing times observed for the fillet models result from the additional elements required to accurately represent the curved weld geometry. However, these differences are considerably smaller than those associated with mesh refinement.

Previous studies have mainly emphasized improving structural hot-spot stress (SHSS) prediction through mesh refinement and weld geometry representation, while comparatively little attention has been given to computational efficiency. The present results show that increasing the mesh density increased the computational time by approximately five to six times, while the corresponding change in SHSS remained below 4%. Therefore, for simple welded plate joints, a structured coarse transfinite mesh provides a practical balance between computational efficiency and prediction accuracy, making it suitable for routine engineering finite element analyses [3], [8], [9], [10], [11], [12].

3.5 Overall comparison of SHSS methods

This study presents a direct comparison of the IIW Linear Stress Extrapolation (LSE) and Haibach methods under identical mesh densities and weld geometry representations. Table 6 summarizes the overall characteristics of the IIW Linear Stress Extrapolation (LSE) and Haibach methods based on the present finite element analyses. Although both methods produced similar trends with respect to mesh density and weld geometry representation, clear differences were observed in the predicted structural hot-spot stress and the required post-processing procedure.

Table 6. Overall comparison all models

Evaluation Criterion	IIW LSE	Haibach
SHSS evaluation	Linear extrapolation using two reference points	Single-point stress readout
Reference locations	0.4t–1.0t (fine), 0.5t–1.5t (coarse)	2-2.5 mm from weld toe
Stress prediction	Higher (more conservative)	Lower
Mesh sensitivity	Low	Low
Weld geometry sensitivity	High	High
Post-processing complexity	Moderate	Simple
Suitable application	Design verification and conservative structural assessment	Preliminary analysis and rapid engineering evaluation

The IIW LSE method consistently produced higher structural hot-spot stress (SHSS) values than the Haibach method because it estimates the structural hot-spot stress by extrapolating stresses from multiple reference points toward the weld toe. In contrast, the Haibach method determines SHSS directly from a single stress value measured at a fixed distance from the weld toe, resulting in a simpler post-processing procedure but consistently lower stress predictions.

The present findings are consistent with those reported by Iqbal et al [9], who observed that the IIW extrapolation procedure provides more consistent structural hot-spot stress predictions than single-point evaluation methods under different meshing strategies. While their study focused on orthotropic steel deck joints subjected to fatigue loading, the present work demonstrates that the same behavior is maintained for a simple welded plate under static loading, indicating that the robustness of the IIW method primarily arises from its extrapolation procedure.

Overall, weld geometry representation had a greater influence on SHSS prediction than mesh density, whereas mesh density had the greatest influence on computational performance. Consequently, explicit weld geometry should be incorporated into finite element models whenever accurate SHSS prediction is required, while a structured coarse transfinite mesh can provide an effective balance between computational efficiency and prediction accuracy.

Based on the present results, the IIW LSE method is recommended for structural integrity assessment and design verification where conservative stress estimation and compliance with IIW recommendations are required. The

Haibach method offers a practical alternative for preliminary engineering analyses and comparative studies where simplified post-processing and reduced implementation effort are preferred.

The findings presented in Tables 1 - 6 collectively demonstrate that the choice of SHSS evaluation method should be guided by the intended engineering application. The IIW LSE method consistently provides more conservative SHSS predictions and is therefore recommended for structural integrity assessment, fatigue-oriented design verification, and applications requiring compliance with IIW recommendations. In contrast, the Haibach method offers a simpler post-processing procedure while maintaining similar prediction trends, making it suitable for preliminary engineering analyses and rapid comparative studies. Furthermore, the results indicate that accurate weld geometry representation contributes more significantly to SHSS prediction than additional mesh refinement, whereas structured coarse meshes provide an effective balance between computational efficiency and prediction accuracy.

4. Conclusions.

This study compared the IIW Linear Stress Extrapolation (LSE) and Haibach methods for structural hot-spot stress (SHSS) evaluation using finite element models with different weld geometry representations and mesh densities. The IIW LSE method consistently produced higher SHSS values than the Haibach method, while both methods showed low sensitivity to mesh refinement, with SHSS differences below 4%. Weld geometry representation had a greater influence on SHSS prediction than mesh density, with the chamfer model producing the highest stress values. Fine meshes increased computational time by approximately five to six times compared with coarse meshes while providing only marginal improvements in SHSS prediction. These results indicate that the IIW LSE method is more suitable for conservative structural integrity assessment and design verification, whereas the Haibach method is appropriate for preliminary engineering analyses requiring simpler post-processing. From an engineering perspective, these findings indicate that the IIW LSE method should be selected when conservative structural assessment and compliance with IIW recommendations are required, whereas the Haibach method provides an efficient alternative for preliminary structural evaluations with reduced post-processing complexity. Future research should extend the comparison to more complex welded joint configurations, different loading conditions, and fatigue life assessment.

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