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Analysis and Structural Design of a 35-Meter-Span Steel Truss Roof System (Truss Frame)

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Abstract

Steel truss systems are widely applied in long-span buildings because their interconnected structural members provide efficient load transfer while enabling large column-free spaces. This study aims to analyze and compare the structural performance of a 35-meter-span steel truss roof system with roof slopes of 15° and 40°. The evaluation considers maximum compressive force, maximum tensile force, structural deflection, member capacity, critical connection capacity, and estimated design cost. Structural analysis was conducted using ETABS, with loading based on SNI 1727:2020 and steel member design based on SNI 1729:2020, while critical truss connections were evaluated using a Finite Element Method (FEM)-based analysis. The structure employs BJ37 steel with a yield strength of 240 MPa and an ultimate tensile strength of 370 MPa, together with ASTM A325 bolts. The 15° configuration produced a maximum compressive force of 245.613 kN, tensile force of 273.233 kN, and deflection of 43.661 mm, whereas the 40° configuration produced 248.547 kN, 196.852 kN, and 28.028 mm, respectively. Both alternatives satisfied the member-capacity and critical-connection requirements, with PPM Ratios below 1.00. The 40° configuration reduced maximum deflection by approximately 35.8%, while the 15° configuration achieved a lower design cost of Rp2,367,220,436.88 compared with Rp3,108,334,653.83 for the 40° configuration. The findings indicate that roof-slope selection requires balancing structural stiffness, force distribution, safety, and economic efficiency.

Keywords: *Bolted Connection, Deflection, ETABS, FEM, Steel Truss Structure.*

INTRODUCTION

Long-span roof structures have become increasingly important in contemporary building development because the demand for large column-free spaces requires structural systems capable of carrying substantial gravity and environmental loads while maintaining adequate stiffness, stability, constructability, and economic efficiency. Steel truss systems represent one of the established structural solutions for such applications because their arrangement of interconnected linear members can efficiently transfer loads through axial forces while producing relatively lightweight structural configurations and large unobstructed interior spaces. Recent investigations have demonstrated that the structural response of steel trusses is strongly influenced by geometric configuration, member arrangement, loading characteristics, and stability conditions, indicating that the selection of an appropriate truss configuration cannot be separated from the overall performance requirements of the structure (Aswadi et al., 2026). The application of steel trusses in large-span roofs also involves practical challenges associated with erection, deformation control, monitoring, and structural reliability, particularly as span lengths increase and structural systems become more sensitive to environmental actions (Hui et al., 2023). For a 35-meter span, the structural system must simultaneously accommodate dead loads, live loads, wind actions, and other applicable design effects without compromising serviceability or ultimate resistance. This condition makes the geometric design of the roof truss an important engineering decision because changes in geometry can alter internal force distribution, member utilization, structural deformation, and material requirements.

The roof slope is one of the geometric parameters that can substantially influence the behavior and efficiency of a long-span truss because it modifies the spatial relationship between the upper and lower chords, the inclination of web members, and the resulting load-transfer mechanism. Previous research on steel truss optimization has shown that structural geometry can be systematically modified to improve material efficiency while satisfying global stability and individual member buckling constraints (Cai et al., 2025). Computational optimization studies have similarly demonstrated that steel truss configurations can produce different structural responses and material demands when geometric and design variables are varied, highlighting the importance of configuration selection during preliminary structural design (Li et al., 2023). Experimental and analytical studies have further established that stability and deformation are critical considerations in steel truss systems because local member behavior and global structural response can interact under demanding loading conditions (Boukhalfa et al., 2024). The influence of geometry becomes particularly relevant for roof structures because increasing roof inclination can modify both the magnitude and direction of load components acting on the truss members. A steeper configuration may provide structural advantages under particular loading conditions while simultaneously affecting member lengths, connection requirements, fabrication complexity, and overall material consumption. The comparison of alternative roof slopes therefore provides a rational basis for determining whether a geometrically different truss configuration can achieve a more balanced relationship between structural safety, serviceability, and design economy.

Structural adequacy in long-span steel roofs cannot be evaluated solely from member axial forces because deformation, buckling, connection behavior, and environmental loading may govern the actual performance of the structural system. Field monitoring of long-span steel roof trusses has emphasized the importance of evaluating both stress and deformation because excessive displacement can indicate unfavorable structural behavior even when individual members remain within their nominal strength limits (Hui et al., 2023). Seismic investigations have also shown that steel truss frames can exhibit complex acceleration and strain responses, particularly when structural instability and post-earthquake buckling become relevant to performance assessment (Iyama et al., 2023). Wind resistance represents another critical design consideration for large-span roof systems because aerodynamic behavior and structural stability can influence the magnitude and distribution of wind-induced responses (Song et al., 2024). At the connection level, the manner in which structural members are joined can affect the global response and resistance characteristics of steel framing systems, making connection design an integral component of structural analysis rather than a secondary detailing exercise (Elhout, 2024). Studies of steel truss connections have also indicated that the interaction between supporting structures and truss connections can significantly influence seismic behavior, reinforcing the need to assess connection capacity alongside member capacity (Cui et al., 2022). These findings indicate that a reliable long-span roof design requires an integrated assessment of member forces, deformation, stability, and connection performance under the governing design actions.

Despite the substantial development of analytical and optimization approaches for steel trusses, the existing literature remains concentrated largely on specialized structural problems, including topology optimization, dynamic response, buckling behavior, seismic performance, and advanced erection methods, rather than on comparative design assessments that simultaneously connect roof geometry with structural capacity and project cost. Research on steel arch bridges, for example, has investigated the optimization of hanger spacing under dynamic loads, demonstrating that structural configuration and load effects are closely associated with the resulting response of steel systems (Bathista et al., 2024). Research on cold-formed steel trusses has also examined the performance of self-drilling screw connections under extreme loading, illustrating that connection behavior can become a critical component of the overall resistance of lightweight truss systems (Mohamed et al., 2025). Other studies have addressed large-span steel roof construction through specialized sliding techniques, demonstrating the importance of considering structural behavior together with construction processes in large-scale roof projects (Lu et al., 2022). Nevertheless, these studies do not directly resolve how alternative roof slopes for a fixed 35-meter span affect the combined outcomes of member forces, structural deformation, member capacity, connection capacity, and planning cost within a single comparative design framework. This limitation is particularly relevant for engineering practice because a structurally safe alternative is not necessarily the most efficient solution when material quantity, connection requirements, and construction-related costs are considered simultaneously. The unresolved relationship between roof geometry, structural performance, and economic efficiency constitutes an empirical gap that warrants a focused comparative investigation.

The engineering significance of this problem is strengthened by the fact that long-span steel structures are required to satisfy codified criteria for loading, strength, stability, and connection design while responding to project-specific geometric and functional requirements. In Indonesia, the determination of minimum design loads and associated structural criteria is governed by SNI 1727:2020, which provides the basis for establishing applicable loads and load combinations for buildings and other structures (Badan Standardisasi Nasional, 2020a). The design and specification of structural steel members are addressed through SNI 1729:2020, providing the fundamental requirements for assessing the strength and stability of steel structural components (Badan Standardisasi Nasional, 2020b). Connection requirements are equally important because the transfer of forces between truss members and supporting components must be demonstrated to possess adequate resistance under the governing structural actions. The importance of robust structural bracing and force-transfer mechanisms is also reflected in comparative investigations of steel structures subjected to dynamic earthquake loads, where alternative bracing configurations produce different structural responses (Nursani et al., 2026). Recent research on steel framing has further demonstrated that structural configuration can influence performance optimization, reinforcing the engineering need to evaluate alternative arrangements rather than relying on a single predetermined geometry (Kusuma et al., 2025). For a 35-meter-span roof, a systematic comparison based on nationally applicable structural standards is therefore necessary to establish whether differences in roof slope produce meaningful changes in structural demand, resistance, deformation, and economic requirements.

This study addresses the identified gap by conducting a comparative analysis and structural design of a 35-meter-span steel truss roof system using two roof-slope alternatives, namely 15° and 40°, while retaining the same fundamental span and functional structural requirements. The analysis focuses on the resulting member forces, structural deformation, member capacity, connection capacity, and design cost so that structural performance can be assessed from both safety and efficiency perspectives. The research specifically aims to determine how changes in roof slope modify the internal force distribution and deformation characteristics of the truss, evaluate the adequacy of the selected structural members against the governing design requirements, and design connections capable of transferring the resulting structural forces safely. The study also compares the estimated planning and construction-related structural costs associated with the two alternatives to identify the configuration that provides the most appropriate balance between structural adequacy and economic efficiency. The methodological contribution lies in integrating geometric comparison, structural analysis, member-capacity verification, connection design, and cost evaluation within one coherent assessment framework for a fixed long-span roof condition. From an engineering perspective, the findings are expected to provide a rational basis for selecting roof-truss geometry in long-span applications where structural safety, serviceability, connection reliability, and cost must be considered concurrently. The resulting framework can also serve as a practical reference for preliminary and detailed structural decision-making in the design of steel truss roofs with comparable span and loading characteristics.

RESEARCH METHODS

This study is classified as a non-empirical structural design study, because no laboratory or field experiment is conducted and the evaluation is based on numerical structural modeling, code-based design verification, finite element analysis, and comparative engineering calculations. The research object is a steel truss roof system for a building measuring 60 m in length and 35 m in width, with a 35 m truss span evaluated under two roof-slope alternatives of 15° and 40°. The conceptual design maintains the same fundamental span, steel grade, and inter-truss spacing for both alternatives, while the purlin spacing and roof covering are adjusted according to each configuration to represent the planned structural conditions. The steel material is BJ37 with a yield strength (fy) of 240 MPa and an ultimate tensile strength (fu) of 370 MPa, while ASTM A325 bolts are specified for the primary bolted connections. The structural configuration consists of interconnected steel members forming a stable triangular truss system, with the geometric arrangement established to transfer roof loads efficiently toward the supports. Variations in truss geometry are considered important because changes in configuration can affect member forces, structural stability, deformation, and material efficiency in steel truss systems (Li et al., 2023). The initial design and numerical modeling stages comprise literature review, collection of planning data, preliminary member sizing, establishment of the two roof-slope alternatives, and preparation of the structural models for subsequent analysis.

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Table 1. Structural and Geometric Parameters of the 35-Meter-Span Steel Truss Roof Alternatives

Parameter	15°	40°
Truss span	35 m	35 m
Steel grade	BJ37	BJ37
fy / *fu*	240 / 370 MPa	240 / 370 MPa
Bolts	ASTM A325	ASTM A325
Distance between trusses	4.5 m	4.5 m
Purlin spacing	1.0 m	1.2 m
Roof covering	UPVC	Ceramic roof tiles

The technical analysis begins by determining the applicable gravity and environmental loads in accordance with SNI 1727:2020, followed by the application of relevant load combinations to the numerical models representing the 15° and 40° roof configurations. Each structural alternative is modeled using ETABS by defining the truss geometry, material properties, member sections, support conditions, purlin spacing, inter-truss spacing, roof loads, and prescribed load combinations so that both configurations can be evaluated under consistent analytical assumptions. Static structural analysis is then performed to obtain axial member forces, support reactions, and nodal displacements, followed by member-capacity verification according to SNI 1729:2020 through strength and stability assessments of the governing tension and compression members. Compression members receive particular attention because buckling behavior is strongly associated with member geometry and effective length, which can influence the resistance and efficiency of steel truss systems (Boukhalfa et al., 2024). Structural serviceability is evaluated by comparing the calculated maximum deformation with the applicable allowable deformation criteria, while member adequacy is assessed using the relationship between factored demand and available design capacity. Critical truss-node connections are subsequently analyzed using a finite element method (FEM)-based model and designed with ASTM A325 bolts, with connection performance evaluated against the applicable connection resistance requirements because the behavior of truss connections can affect the structural response and load-transfer mechanism of the overall system (Cui et al., 2022). The final comparison evaluates member forces, maximum deformation, member capacity utilization, critical connection capacity, structural requirements, and estimated design cost for the 15° and 40° alternatives, thereby establishing the configuration that provides the most appropriate balance between structural safety, serviceability, stability, and economic efficiency.

RESULTS AND DISCUSSION

Comparison of Member Forces and Structural Deflection

The numerical analysis of the 35-meter-span steel truss produced different internal force and deformation responses for the 15° and 40° roof-slope configurations, indicating that roof geometry directly influences the structural behavior of the truss system. Both alternatives were analyzed using the same fundamental span of 35 m, steel grade BJ37, and inter-truss spacing of 4.5 m, allowing the influence of roof inclination to be interpreted within the defined design conditions. The principal results obtained from the structural analysis are presented in Table 2, which summarizes the maximum compressive force, maximum tensile force, and maximum structural deflection for both alternatives. The maximum compressive force increased slightly from 245.613 kN at 15° to 248.547 kN at 40°, representing an increase of approximately 1.20%, whereas the maximum tensile force decreased from 273.233 kN to 196.852 kN. This contrasting response indicates that increasing the roof slope does not uniformly reduce or increase internal forces, but instead redistributes the axial force demand among the truss members according to the modified structural geometry. Similar sensitivity of steel structural response to configuration has been identified in comparative studies in which changes in structural arrangement altered force distribution and overall resistance characteristics (Aswadi et al., 2026). The numerical differences therefore provide an important basis for assessing the relative structural efficiency of the two roof configurations rather than evaluating roof slope solely from geometric considerations.

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Table 2. Comparison of Member Forces and Structural Deflection

Parameter	15°	40°
Maximum compressive force	245.613 kN	248.547 kN
Maximum tensile force	273.233 kN	196.852 kN
Maximum deflection	43.661 mm	28.028 mm

As indicated in Table 2, the most pronounced difference between the two configurations occurs in maximum structural deflection, where the 40° roof produces a considerably smaller displacement than the 15° roof. The maximum deflection decreases from 43.661 mm to 28.028 mm, corresponding to a reduction of approximately 35.8%, while the span remains unchanged at 35 m. Such a reduction indicates that the steeper truss configuration provides a more favorable deformation response under the applied design loading, even though its maximum compressive force is marginally higher. The deformation behavior is particularly relevant for long-span roof structures because serviceability performance depends not only on member strength but also on the ability of the structural system to control displacement under operational loading. Monitoring research on long-span steel roof trusses similarly emphasizes stress and deformation as important indicators for evaluating structural performance and serviceability (Hui et al., 2023). The lower displacement obtained for the 40° configuration suggests that its geometry provides a more effective load-transfer mechanism and greater global stiffness under the modeled loading conditions. This finding is consistent with the broader principle that changes in truss geometry can modify structural efficiency by influencing the relationship between member orientation, axial force, and overall deformation.

The reduction in tensile force at the 40° configuration is also structurally significant because the maximum tensile demand decreases by approximately 27.96% compared with the 15° configuration. In contrast, the maximum compressive force increases by only approximately 2.934 kN, showing that the principal effect of increasing the roof slope is associated more strongly with redistribution of tensile demand than with an overall increase in axial force intensity. The geometry of a truss determines the inclination and effective contribution of its web and chord members, which subsequently changes the magnitude and direction of axial forces required to equilibrate the applied loads. A configuration that produces lower tensile demand may reduce the required resistance of particular tension members, although the resulting compression demand must still be assessed because compression resistance is sensitive to stability and buckling effects. Research on truss optimization has demonstrated that global stability and member buckling constraints must be considered together when evaluating structural configurations, since a reduction in one response parameter does not necessarily indicate superior structural performance across all criteria (Cai et al., 2025). The present results therefore indicate that the 40° alternative has a more favorable force distribution in terms of maximum tensile demand, but this advantage must be interpreted alongside its slightly higher compression demand and subsequent member-capacity requirements.

The deformation difference between the alternatives can also be interpreted through the relationship between truss depth and structural stiffness, because a steeper roof modifies the vertical geometry of the truss and can increase the structural depth available for resisting transverse loads. The 40° configuration achieves a maximum displacement of only 28.028 mm, compared with 43.661 mm for the 15° configuration, indicating that the geometric modification substantially changes the stiffness characteristics of the modeled system. The resulting 35.8% reduction in maximum deflection is particularly relevant for a 35-meter span because long-span structures can experience significant deformation even when member forces remain within their design resistance. Previous analytical research on steel trusses has shown that member geometry and effective buckling characteristics are closely connected to structural stability, particularly for members subjected to compression (Boukhalfa et al., 2024). The lower deflection obtained at 40° therefore suggests a potentially more favorable stiffness response, although it should not be interpreted independently from member stability and connection performance. The result also illustrates why a structural alternative should be evaluated through multiple performance indicators rather than through a single maximum-force criterion. From a design perspective, the 40° configuration provides a clear serviceability advantage, whereas the 15° configuration retains a lower maximum compressive demand, creating a performance trade-off that requires further evaluation through capacity and economic analyses.

The force and deformation patterns further demonstrate that the two roof configurations cannot be regarded as structurally equivalent simply because they have the same 35-meter span and use the same BJ37 steel material. The 15° configuration develops the higher tensile demand of 273.233 kN, while the 40° configuration develops the higher compressive demand of 248.547 kN, revealing a shift in the governing axial-force mechanism caused by the change in roof geometry. This shift has implications for member selection because tensile members are primarily governed by tensile resistance and connection-related limit states, whereas compression members require greater consideration of effective length, slenderness, and buckling resistance. Studies of steel trusses subjected to initial geometric and loading imperfections have shown that compression stability and postbuckling behavior can substantially influence structural response under demanding conditions (Dao et al., 2025). The present numerical results do not indicate structural failure at the level of force and displacement comparison, but they establish different demand conditions that must subsequently be checked against the available member capacities. The 40° configuration can therefore be interpreted as structurally stiffer but more compression-demanding, while the 15° configuration is more tensile-demanding and less favorable in terms of maximum deformation. This distinction provides the analytical basis for the member-capacity assessment because the suitability of each configuration ultimately depends on whether the governing demands remain within the resistance limits prescribed for the selected steel profiles.

From an overall structural-performance perspective, the results indicate that increasing the roof slope from 15° to 40° produces a meaningful improvement in deformation control while substantially reducing the maximum tensile force, although the maximum compressive force increases slightly. The 35.8% reduction in maximum deflection is the most prominent performance improvement and suggests that the steeper configuration has greater effectiveness in controlling serviceability response under the specified loading conditions. At the same time, the increase in maximum compressive force means that the structural benefit cannot be assessed solely through deformation because compression-member stability may become more influential in determining the adequacy of the selected profiles. Comparative investigations of long-span truss systems have shown that structural configuration can affect both performance and material efficiency, supporting the use of multiple criteria when selecting an appropriate structural arrangement (Utami et al., 2025). The results obtained in this study establish a clear performance distinction between the alternatives: the 40° roof provides lower deformation and tensile-force demand, whereas the 15° roof produces a slightly lower maximum compression demand. These findings provide the analytical basis for the subsequent evaluation of member capacity, critical structural elements, and stability requirements. The comparison indicates that roof-slope selection should integrate force response and deformation with member resistance, connection adequacy, and construction cost rather than relying on geometric preference alone.

Member Capacity and Structural Stability Assessment

The member-capacity assessment was conducted to determine whether the steel profiles selected for the 35-meter-span truss could safely resist the governing axial forces obtained from the structural analysis. The evaluation used the PPM Ratio as the principal indicator, where a value below 1.00 represents a member demand that remains within the corresponding design capacity. The assessment was performed for both roof-slope alternatives because the different geometries generated different distributions of compression and tension forces, as identified in the preceding structural response analysis. The capacity verification is particularly important for the present system because the maximum compressive force increased slightly from 245.613 kN at 15° to 248.547 kN at 40°, while the maximum tensile force exhibited the opposite trend. The governing member was therefore not identified solely from the magnitude of axial force, but from the relationship between structural demand and the resistance of the selected cross-section. This approach is consistent with steel-truss optimization studies that treat member resistance and global stability as interrelated design constraints rather than independent criteria (Cai et al., 2025). The resulting PPM Ratio provides a quantitative basis for determining whether the selected profiles remain adequate under the governing load combinations.

The numerical verification indicates that the examined members in both configurations have PPM Ratios below the limiting value of 1.00, indicating that the calculated structural demands do not exceed the available design capacities. For the 40° configuration, the highest reported PPM Ratio is 0.872, occurring in the 2L 100.100.10 profile, which represents a utilization level of approximately

87.2% of the corresponding design capacity. The remaining margin indicates that the governing member retains approximately 12.8% capacity relative to the adopted demand-to-capacity criterion, although this margin should not be interpreted as an equivalent factor of safety because the PPM Ratio incorporates the applicable design provisions and load effects. The 15° configuration also produces PPM Ratios below 1.00, confirming that the selected members satisfy the adopted capacity criterion under the analyzed loading conditions. The capacity results are summarized in Table 3 to distinguish the governing utilization response between the two roof-slope alternatives. The relatively high utilization of the 40° critical member is consistent with the slightly higher maximum compressive force observed for this configuration, demonstrating that changes in roof geometry can alter the distribution of demand among individual members.

Table 3. Member Capacity Verification Based on PPM Ratio

Parameter	15°	40°
Maximum PPM Ratio	< 1.000	0.872
Governing profile	Selected steel member	2L 100.100.10
Capacity criterion	PPM Ratio < 1.000	PPM Ratio < 1.000
Design status	Pass	Pass

The capacity results demonstrate that both roof configurations satisfy the adopted member-strength criterion despite their different internal force distributions. The 40° alternative approaches a higher utilization level in its governing member, but its maximum PPM Ratio of 0.872 remains below the critical value of 1.00 and therefore indicates an acceptable member demand under the design assumptions. The result also shows that a higher roof slope does not automatically lead to lower utilization across every member, even though it produces a substantially smaller maximum structural deflection. Compression members require particular attention because their resistance depends not only on material strength but also on geometric slenderness, effective length, and buckling behavior. Analytical investigations of steel trusses have demonstrated that the determination of effective buckling characteristics is essential for accurately evaluating compression-member resistance and overall structural stability (Boukhalfa et al., 2024). The PPM Ratio results should therefore be interpreted together with the stability characteristics of the selected profiles rather than as an isolated numerical acceptance check.

The difference in utilization behavior can be related to the changes in truss geometry generated by the two roof slopes, which modify member lengths, inclination angles, and the distribution of axial forces within the structural system. The 40° configuration produces a slightly greater maximum compression force than the 15° configuration, while simultaneously producing a lower tensile force and lower overall deflection, indicating that the structural response is redistributed rather than uniformly improved or deteriorated. Such redistribution is relevant to member design because the governing profile may shift when the geometry changes, even when the span, steel grade, and inter-truss spacing remain constant. The stability of compression members becomes increasingly significant when the design response is controlled by slender elements, since instability can occur before the nominal yield resistance of the steel is reached. Research on steel trusses under imperfect initial conditions has emphasized the sensitivity of compression systems to buckling and postbuckling phenomena, particularly when geometric imperfections interact with mechanical loading (Dao et al., 2025). The present PPM Ratio assessment does not indicate an inadequate member for either alternative, but the 40° configuration requires closer attention to its governing compression member because its utilization level is higher. This observation reinforces the need to evaluate member capacity as part of an integrated structural-performance assessment rather than selecting the preferred roof slope from deflection results alone.

The adequacy of the selected profiles is also relevant to the practical efficiency of the truss because excessive member capacity can indicate unnecessary material use, whereas utilization values approaching or exceeding the design limit can reduce robustness against variations in loading and structural behavior. The maximum PPM Ratio of 0.872 for the 40° configuration suggests relatively efficient utilization of the governing 2L 100.100.10 profile while retaining compliance with the adopted design criterion. For the 15° configuration, the available result confirms compliance because the reported PPM Ratios remain below 1.00, although a precise comparison of its governing utilization with the 40° alternative requires the complete member-check output. Structural optimization literature supports this interpretation by emphasizing that efficient truss design requires simultaneous consideration of member resistance, buckling constraints, and global structural stability (Li et al., 2023). The capacity verification therefore confirms that the differences in roof geometry do not result in an unacceptable member response within the modeled design conditions. The result is particularly important because the 40° configuration, despite its higher compression demand, remains within the available member resistance and can consequently proceed to the evaluation of critical connections. Member adequacy is thus established as a necessary condition for comparing the two alternatives, while it does not by itself determine the most economical or globally preferable configuration.

From the perspective of structural safety, both alternatives demonstrate acceptable member performance because their governing PPM Ratios remain below the adopted limiting value of 1.00. The 40° configuration records a maximum utilization of 0.872, which indicates that the governing 2L 100.100.10 member remains within its available resistance despite being subjected to the higher maximum compressive force. The 15° configuration likewise satisfies the capacity requirement based on the reported PPM Ratio results, although its higher tensile force and greater deflection produce a different overall performance profile. This distinction is important because structural adequacy encompasses more than resistance against a single governing force and should include stiffness, stability, and load-transfer behavior. Comparative studies of steel framing have shown that changes in structural configuration can modify performance characteristics and that optimization requires consideration of multiple structural response parameters (Kusuma et al., 2025). The present assessment establishes that neither roof slope produces a member-capacity failure under the specified analytical conditions. The next stage of evaluation therefore focuses on the critical truss connections, where the calculated member forces must be transferred safely through plates and ASTM A325 bolts to maintain the integrity of the complete structural system.

Critical Connection Analysis and Capacity Verification

The connection assessment was performed to verify the ability of the critical truss joints to transfer the axial forces generated by the structural analysis without exceeding the resistance of the connection components. The analysis focused on critical nodes identified from the governing member-force response because these locations represent the points where force transfer between chord and web members can produce concentrated demands on bolts, plates, and connected elements. The connection model was evaluated using a finite element method (FEM)-based approach to obtain the structural response of the critical joint under the corresponding design forces. The use of numerical connection analysis is appropriate for steel truss systems because the local behavior of a joint may differ from the idealized member response represented in the global structural model. Previous research on steel space-truss connections has demonstrated that connection behavior can influence the response and load-transfer characteristics of the structural system, particularly under demanding loading conditions (Cui et al., 2022). The assessment therefore considered both the connection response and the capacity of the principal components, including the connection plate and ASTM A325 bolts. The resulting verification provides a complementary assessment to the member-capacity analysis because a structurally adequate truss member cannot ensure overall structural reliability if the force-transfer mechanism at its critical joints is inadequate.

The critical connection was evaluated using the forces obtained from the ETABS structural analysis for the corresponding roof configuration, with the connection geometry and component properties defined according to the design assumptions established in the methodology. The principal verification parameters consisted of the applied connection force, plate response, bolt resistance, and overall connection adequacy under the governing load condition. The analytical procedure was structured to identify whether local stresses and force demands remained compatible with the available resistance of the connection components. The principal outcome of the connection assessment is summarized in Table 4, which presents the verification status of the critical connection components for the two roof-slope alternatives. The results show that the analyzed connections satisfy the applicable design requirements, indicating that the force generated by the global truss analysis can be transferred through the designed connection without producing an unacceptable connection response. This finding is consistent with research demonstrating that connection configuration and force-transfer characteristics can influence the structural response of steel framing systems (Elhout, 2024). The connection verification consequently supports the continuation of the comparative assessment toward the economic evaluation of the two roof configurations.

Table 4. Critical Connection Verification Results

Connection Component	15°	40°
Critical connection location	Critical truss node	Critical truss node
Connection type	Bolted connection	Bolted connection
Bolt specification	ASTM A325	ASTM A325
Plate verification	Satisfactory	Satisfactory
Bolt verification	Satisfactory	Satisfactory
Overall connection status	Pass	Pass

The results in Table 4 indicate that both connection alternatives meet the adopted design requirements for the critical truss node, including the verification of the connection plate and ASTM A325 bolts. The satisfactory response is particularly important because the 15° and 40° configurations generate different combinations of tensile and compressive member forces, which means that the connection system must accommodate different force-transfer demands. The higher tensile demand recorded for the 15° configuration does not result in an inadequate connection under the adopted design conditions, while the slightly higher compression demand in the 40° configuration likewise remains compatible with the designed connection capacity. Connection adequacy should be interpreted as a system-level requirement because local failure at a joint can interrupt the intended load path even when the connected members individually satisfy their strength requirements. Research on steel truss connections has shown that joint behavior is closely related to the interaction between the connected members and supporting structural components, particularly when force transfer becomes concentrated at critical nodes (Cui et al., 2022). The present results indicate that the designed connection provides sufficient resistance for the governing forces obtained from the numerical structural model. This establishes that the difference in roof geometry does not compromise the basic integrity of the selected connection arrangement within the defined design conditions.

The FEM-based assessment provides an additional perspective because global truss analysis generally idealizes members and joints according to simplified structural assumptions, whereas a detailed connection model can represent localized stress distribution and deformation around the joint. This distinction is important for long-span steel trusses because relatively high axial forces can be transferred through compact connection regions, potentially generating local demand that is not directly apparent from the global member-force output. The connection analysis therefore serves as a verification step between the idealized global structural response and the physical force-transfer mechanism expected at the critical node. Research concerning screw-connected cold-formed steel trusses under extreme loads similarly demonstrates that the behavior of fastening systems can become an important determinant of connection performance under high demand (Mohamed et al., 2025). In the present study, the satisfactory plate and bolt verification indicates that the connection components provide adequate resistance for the calculated design forces. The result also supports the validity of using the selected connection arrangement for both roof-slope alternatives without introducing a connection-controlled structural deficiency. Further assessment of the complete structural system can therefore focus on the relative efficiency of the alternatives rather than on remediation of an identified critical connection failure.

The connection response must also be considered in relation to the force redistribution identified in the preceding member analysis, particularly because the 15° configuration produces a substantially greater maximum tensile force while the 40° configuration produces a slightly greater maximum compressive force. These differences imply that the governing connection demand may arise from different load-transfer mechanisms even when both alternatives use the same ASTM A325 bolt specification. A reliable connection design must accommodate the direction, magnitude, and combination of forces transmitted by the connected truss members rather than being selected solely from the nominal member profile. The importance of this consideration is supported by studies showing that structural response can vary according to connection type and its interaction with the surrounding steel framing system (Elhout, 2024). The present analysis confirms that the critical connections remain adequate under the respective governing conditions, indicating that neither roof slope generates a connection demand beyond the designed resistance. The connection results consequently complement the member-capacity findings, in which both configurations also satisfied the PPM Ratio criterion. Taken together, these results indicate that the structural alternatives possess acceptable member and connection resistance, allowing economic performance to become an important differentiating criterion.

The adequacy of the critical connections also contributes to the reliability of the overall load path from the roof covering and purlins through the truss members and ultimately to the supports. A connection that satisfies its component-level resistance requirements provides continuity within this load path and reduces the likelihood that local connection behavior will govern the global structural response. The present analysis demonstrates that the designed plate and bolt arrangements remain satisfactory for the critical nodes considered in both configurations, despite the different internal-force patterns produced by the roof slopes. This result is consistent with the broader engineering principle that structural performance should be evaluated through the combined behavior of members and their force-transfer interfaces rather than through isolated member checks. Investigations of steel structures subjected to dynamic actions have similarly emphasized that changes in structural configuration can alter load paths and response characteristics, reinforcing the importance of evaluating the complete structural arrangement (Nursani et al., 2026). The connection results therefore provide evidence that the selected truss configurations maintain an acceptable force-transfer mechanism under the analyzed design conditions. With member and connection adequacy established, the comparison can proceed to the cost evaluation, where differences in structural requirements, roof covering, purlin spacing, and accessories determine the economic implications of each alternative.

Comparative Cost and Overall Structural Performance

The economic assessment compares the estimated costs of the 15° and 40° steel truss roof alternatives after the structural analyses, member-capacity checks, and critical connection evaluations were completed. The comparison is important because structural adequacy alone does not determine the most efficient design when alternative geometries require different quantities of structural material, roof-covering systems, purlin arrangements, and accessories. The calculated costs indicate that the 15° configuration requires a lower total expenditure than the 40° configuration, although the latter provides superior deformation performance based on the preceding analysis. The cost components used in the comparison consist of structural work, roof covering, and accessories, allowing the economic difference to be examined according to its principal contributors. The resulting values are presented in Table 5, where the subtotal for each alternative represents the combined cost of the three components. This type of comparative evaluation is relevant to long-span structural design because material efficiency and structural performance are closely related to the selected structural configuration (Utami et al., 2025). The economic results therefore provide an additional decision criterion for determining the relative suitability of the two roof-slope alternatives.

Table 5. Cost Comparison of the 15° and 40° Steel Truss Roof Alternatives

Cost Component	15°	40°
Structural work	Rp1,527,491,624.72	Rp2,374,032,856.31
Roof covering	Rp817,682,688.16	Rp700,933,185.52
Accessories	Rp22,036,124.00	Rp33,368,612.00
Subtotal	**Rp2,367,220,436.88**	**Rp3,108,334,653.83**

As shown in Table 5, the total estimated cost of the 15° configuration is Rp2,367,220,436.88, whereas the 40° configuration requires Rp3,108,334,653.83. The difference reaches approximately Rp741.11 million, meaning that the 15° alternative is approximately 23.85% less expensive than the 40° alternative based on the defined design configurations. The largest contributor to this difference is structural work, which increases from Rp1,527,491,624.72 for the 15° configuration to Rp2,374,032,856.31 for the 40° configuration. This increase indicates that the steeper roof geometry requires a greater structural expenditure under the material and configuration assumptions adopted in the design. Research on optimization of steel structural systems has demonstrated that changes in configuration can influence material requirements and structural efficiency, making economic assessment an important complement to strength and stability verification (Kusuma et al., 2025). The result is particularly relevant because the 40° configuration does not achieve its lower deformation through a lower structural cost, indicating the existence of a clear trade-off between stiffness performance and economic efficiency. The cost comparison should therefore be interpreted together with the force and deformation results rather than as an independent measure of design quality.

An important feature of the cost comparison is that the roof-covering cost behaves differently from the structural-work cost between the two alternatives. The 15° configuration has a roof-covering cost of Rp817,682,688.16, which is higher than the Rp700,933,185.52 required for the 40° configuration, even though the total cost of the 15° alternative remains substantially lower. This difference reflects the use of different roof-covering systems and should not be interpreted as an inherent consequence of roof slope alone. The 15° configuration uses UPVC roofing with 1.0 m purlin spacing, whereas the 40° configuration uses ceramic roof tiles with 1.2 m purlin spacing, meaning that material selection and spacing assumptions contribute directly to the resulting cost structure. The accessories also show a higher cost for the 40° alternative, increasing from Rp22,036,124.00 to Rp33,368,612.00. Cost comparisons in structural systems are most meaningful when differences in material configuration and construction requirements are explicitly retained because structural alternatives may achieve similar functional objectives through different material and assembly strategies (Laksana & Kardiman, 2022). The present results consequently demonstrate that the economic advantage of the 15° alternative arises primarily from its lower structural-work cost rather than from uniformly lower costs across every component.

When the economic results are considered alongside the structural response, the two alternatives demonstrate distinct performance profiles rather than a universally superior configuration. The 40° roof provides a maximum deflection of 28.028 mm compared with 43.661 mm for the 15° roof, representing an approximately 35.8% reduction in maximum displacement, while its maximum compressive force is only slightly higher at 248.547 kN compared with 245.613 kN. The 15° alternative, in contrast, produces the higher maximum tensile force of 273.233 kN but achieves a substantially lower total design cost. The member-capacity assessment indicates that both alternatives remain within the adopted PPM Ratio criterion, while the critical connection assessment confirms satisfactory performance of the analyzed connection components. This combination indicates that the 40° alternative offers a stronger serviceability response without producing an identified member or connection failure, but the improvement is accompanied by a substantially higher estimated project cost. Long-span roof studies emphasize the importance of integrating structural behavior, stability, and practical design requirements when assessing alternative configurations rather than optimizing a single structural response parameter (Li et al., 2023). The results therefore establish a multidimensional trade-off in which deformation performance favors the 40° configuration, whereas economic efficiency favors the 15° configuration.

The relationship between structural cost and deformation also provides insight into the practical implications of roof-slope selection for long-span steel structures. The additional expenditure associated with the 40° alternative produces a significant reduction in maximum deflection, suggesting that part of the increased structural investment is associated with obtaining a stiffer structural configuration. The improvement in deformation performance may be valuable where stringent serviceability requirements, architectural considerations, or operational constraints place greater importance on displacement control than on minimum initial construction cost. However, the present design objective includes both structural adequacy and economic efficiency, so a higher cost cannot be justified solely by a lower deflection unless the additional performance provides a corresponding functional benefit. Research involving long-span roof monitoring has highlighted the importance of controlling deformation because excessive displacement can become a significant indicator of structural performance during service (Hui et al., 2023). Within the conditions analyzed in this study, both alternatives satisfy the member and connection requirements, reducing the need to select the more expensive configuration solely on the basis of structural safety. The economic difference therefore becomes a meaningful factor in selecting between two structurally acceptable alternatives with different stiffness characteristics.

The comparative findings also indicate that the cost advantage of the 15° configuration should be understood within the specific assumptions governing roof covering, purlin spacing, structural arrangement, and material quantities. The 23.85% lower subtotal does not mean that a 15° roof is inherently less expensive than a 40° roof in every project, because changes in material specifications, loading, geometry, fabrication requirements, and architectural constraints could alter the relative costs. The present comparison instead establishes the economic consequence of the two configurations under the defined 35-meter span and associated design parameters. This distinction is essential in structural optimization because the most economical solution depends on the interaction between geometry, member demand, material efficiency, and functional requirements. Studies of steel truss optimization have demonstrated that alternative configurations can produce different combinations of structural performance and material demand, supporting project-specific comparative evaluation rather than universal preference for a particular geometry (Cai et al., 2025). The present findings show that the 15° configuration provides a substantial cost advantage while maintaining acceptable member and connection performance, whereas the 40° configuration provides superior deformation control at a higher cost. The final selection can therefore be based on the relative priority assigned to serviceability and economic efficiency within the project objectives.

Considering the combined results of member forces, deformation, member capacity, connection adequacy, and cost, the two alternatives demonstrate different engineering advantages that must be interpreted within the defined design criteria. The 40° configuration achieves the lower maximum deflection of 28.028 mm and substantially reduces the maximum tensile force, but it also produces a slightly higher maximum compressive force and a total cost of Rp3,108,334,653.83. The 15° configuration produces the higher maximum deflection and tensile force, yet its member-capacity and connection checks remain satisfactory and its total cost is Rp2,367,220,436.88. From an economic-efficiency perspective, the 15° configuration provides the more favorable result because its cost is approximately 23.85% lower while maintaining compliance with the evaluated structural requirements. From a serviceability perspective, the 40° configuration is advantageous because its maximum deflection is approximately 35.8% lower under the analyzed loading conditions. The combined assessment therefore demonstrates that roof-slope selection is fundamentally a multi-criteria structural-design decision in which strength, stability, stiffness, connection performance, and cost must be evaluated simultaneously, consistent with the broader principles of performance-oriented steel structural design (Paronesso & Lignos, 2022).

CONCLUSION

The structural analysis of the 35-meter-span steel truss roof demonstrates that roof inclination produces distinct differences in internal forces and deformation response between the two evaluated configurations. The 15° configuration generated a maximum compressive force of 245.613 kN, a maximum tensile force of 273.233 kN, and a maximum deflection of 43.661 mm, whereas the 40° configuration generated a maximum compressive force of 248.547 kN, a maximum tensile force of 196.852 kN, and a maximum deflection of 28.028 mm. The 40° configuration therefore reduced the maximum deflection by approximately 35.8% relative to the 15° configuration, indicating a more favorable deformation response for the analyzed 35-meter span. Despite the slightly higher maximum compressive force, the 40° configuration exhibited a substantially lower maximum tensile demand, reflecting the influence of truss geometry on axial-force distribution. The member-capacity assessment confirmed that both alternatives satisfy the adopted design criterion because the calculated PPM Ratios remained below 1.00, with the highest reported value for the 40° configuration being 0.872 for the 2L 100.100.10 profile. The critical truss-node connection assessment also indicated satisfactory capacity of the analyzed plates and ASTM A325 bolts under the governing design forces. These findings establish that both roof configurations are structurally acceptable under the defined numerical design conditions, while the 40° configuration provides a superior deformation response.

From an economic perspective, the structural performance advantage of the 40° configuration is accompanied by a substantially higher estimated design cost under the material and geometric assumptions adopted in this study. The 15° configuration produces a subtotal cost of Rp2,367,220,436.88, whereas the 40° configuration requires Rp3,108,334,653.83, resulting in a difference of approximately Rp741.11 million. The 15° alternative is therefore approximately 23.85% more economical than the 40° alternative within the evaluated configuration. The lower cost is primarily associated with the substantially smaller structural-work expenditure of the 15° alternative, although the roof-covering and accessory costs differ because the two configurations use different roof-covering systems and purlin spacing. The final comparison indicates that the 40° configuration is preferable when lower structural deflection and reduced tensile demand are prioritized, while the 15° configuration provides a more favorable balance between structural adequacy and construction economy. The study contributes a comparative numerical framework for evaluating long-span steel truss roof alternatives by integrating member-force response, deformation, capacity utilization, critical connection performance, and estimated cost within a single design assessment. Future research should maintain identical roof-covering materials and purlin configurations across different roof slopes to isolate the direct influence of roof inclination on structural quantity and cost, while additional variations in steel profiles, truss configuration, inter-truss spacing, and connection systems could be investigated to identify more material-efficient and economically optimized designs.

REFERENCES

Aswadi, L. S., Yuwana, D. S. A., Wajdi, B. A., Bhanuwati, A., & Daffa, R. (2026). Effect of steel truss configuration on bridge structural strength and seismic response. *Jurnal Teknik Sipil dan Perencanaan, 28*(1), 39–49. https://doi.org/10.15294/jtsp.v28i1.47805

Badan Standardisasi Nasional. (2020a). *SNI 1727:2020: Beban desain minimum dan kriteria terkait untuk bangunan gedung dan struktur lain*. Badan Standardisasi Nasional.

Badan Standardisasi Nasional. (2020b). *SNI 1729:2020: Spesifikasi untuk bangunan gedung baja struktural*. Badan Standardisasi Nasional.

Badan Standardisasi Nasional. (2020c). *SNI 7972:2020: Sambungan terprakualifikasi untuk rangka momen khusus dan menengah baja pada aplikasi seismik*. Badan Standardisasi Nasional.

Bathista, M. D., Sulasmono, R. I., & Risdanareni, P. (2024). Optimization of hanger spacing of steel arch bridges using dynamic loads. *INERSIA: Informasi dan Ekspose Hasil Riset Teknik Sipil dan Arsitektur, 20*(1), 86–96. https://doi.org/10.21831/inersia.v20i1.67074

Boukhalfa, D., Belaid, T., Slimani, A., & Ammari, F. (2024). Analytical model for buckling length coefficient determination in steel trusses: A lateral torsional buckling approach. *International Journal for Computational Civil and Structural Engineering, 20*(2), 141–154. https://doi.org/10.22337/2587-9618-2024-20-2-141-154

Cai, Q., Ma, J., Xie, Y. M., Zhang, Y., & Zhou, Y. (2025). Topology optimization of trusses considering global stability and member buckling. *Journal of Constructional Steel Research, 226*, 109205. https://doi.org/10.1016/j.jcsr.2024.109205

Cui, Y., Yang, X., Liu, H., & Yamada, S. (2022). Seismic behavior of steel space truss connections to reinforced concrete supporting columns. *International Journal of Steel Structures, 25*(8). https://doi.org/10.1177/13694332211062331

Dao, N. T., Chu, T. H. A., & Chu, T. B. (2025). Thermomechanical buckling and postbuckling of steel trusses with initial load and length imperfection. *The Structural Design of Tall and Special Buildings*. https://doi.org/10.1002/tal.70045

Elhout, E. A. (2024). Effect of beam-column connection types on the response modification factors of steel frames. *International Journal of Steel Structures, 24*, 132–143. https://doi.org/10.1007/s13296-023-00805-4

Hui, C., Jiao, Y., Liu, M., & Hai, R. (2023). Investigation and analysis of stress and deformation monitoring of long-span steel roof trusses. *Buildings, 13*(2), 398. https://doi.org/10.3390/buildings13020398

Iyama, J., Ou, C. C., Yamada, S., Chiba, K., & Toyoshima, M. (2023). Shaking table test of steel truss frame focusing on acceleration and strain response for post-earthquake buckling evaluation. *Bulletin of Earthquake Engineering, 21*, 2759–2783. https://doi.org/10.1007/s10518-023-01633-x

Kusuma, K. A. T., Nindyawati, N., Sulaksitaningrum, R., & Muhammad, D. F. (2025). Structural performance optimization of multi-story steel frames with Split-K EBF bracing system configuration. *INERSIA: Informasi dan Ekspose Hasil Riset Teknik Sipil dan Arsitektur, 21*(1), 81–90. https://doi.org/10.21831/inersia.v21i1.78431

Laksana, N. Y., & Kardiman. (2022). Proses produksi H-beam dengan proses welded beam di PT. Gunung Raja Paksi Tbk. *Jurnal SIGMAT Teknik Mesin UNSIKA, 2*(1), 38–45. https://doi.org/10.35261/sigmat.v2i1.6750

Li, P., Zhao, X., Ding, D., Li, X., Zhao, Y., Ke, L., Zhang, X., & Jian, B. (2023). Optimization design for steel trusses based on a genetic algorithm. *Buildings, 13*(6), 1496. https://doi.org/10.3390/buildings13061496

Lu, C., Yang, Z., Li, P., Xu, Q., Chen, L., & Zhang, C. (2022). Integral sliding of a 800 T steel roof truss for a cultural and art center building. *Case Studies in Construction Materials*, *17*, e01345. https://doi.org/10.1016/j.cscm.2022.e01345

Mohamed, E. M., Hani, S., Elemam, H., Elbelbisi, A., & Elsisi, A. (2025). Performance of CFS trusses self-drilling screws connections under extreme loads. *Structures, 74*, 108592. https://doi.org/10.1016/j.istruc.2025.108592

Nursani, R., Al Huseinny, M. S., & Hidayanto, H. (2026). Comparative analysis on structural behaviour of steel structure using different types of bracing due to dynamic earthquake loads. *INERSIA: Informasi dan Ekspose Hasil Riset Teknik Sipil dan Arsitektur, 21*(2), 240–250. https://doi.org/10.21831/inersia.v21i2.85479

Paronesso, M., & Lignos, D. G. (2022). Seismic design and performance of steel concentrically braced frame buildings with dissipative floor connectors. *Earthquake Engineering & Structural Dynamics, 51*, 3505–3525. https://doi.org/10.1002/eqe.3733

Setiawan, A. (2015). *Struktur baja: Metode elemen hingga dan analisis struktur*.

Song, W., Liu, H., & Yu, H. (2024). Probabilistic evaluation method of wind resistance of membrane roofs based on aerodynamic stability. *Buildings, 14*(12), 3725. https://doi.org/10.3390/buildings14123725

Utami, R., Keintjem, M., Suwondo, R., & Altaee, M. (2025). Comparative analysis of space truss and conventional truss systems in long-span structures: Performance and material efficiency. *IOP Conference Series: Earth and Environmental Science, 1564*(1), 012031. https://doi.org/10.1088/1755-1315/1564/1/012031

Yao, X., et al. (2025). Design and implementation of health monitoring system for an airport terminal building with a large-span truss steel structure. *Buildings, 15*(18), 3308. https://doi.org/10.3390/buildings15183308