

Available online at: <http://journal.unj.ac.id>

Jurnal
Pensil

Pendidikan Teknik Sipil

Journal homepage: <http://journal.unj.ac.id/unj/index.php/jpensil/index>



DETERMINATION OF THE STRUCTURAL PARAMETERS OF TRAPEZOIDAL CHANNEL NUMERICALLY

Anthony Costa^{1}, K.M. Aminuddin², Rosidawani³*

¹ Student in the Professional Engineering Degree Program, Faculty of Engineering, Universitas Sriwijaya, Palembang, South Sumatera, 30139, Indonesia

^{1,2,3} Department of Civil Engineering, Faculty of Engineering, Universitas Sriwijaya, Palembang-Prabumulih Highway Km 32, Indralaya, Ogan Ilir, 30662, Indonesia

^{*1}anthonycosta@ft.unsri.ac.id, ²kmaminuddin@ft.unsri.ac.id, ³rosidawani@unsri.ac.id

Abstract

In this study, the effects of one geometric parameter, the upper width of a reinforced-concrete trapezoidal irrigation channel, on its finite-element response is examined. Three ETABS shell models were analysed to compare the responses of the models using the same bottom width and height, shell material properties, loading types and support assumptions, but different top widths. The comparison is based on the maximum displacement along with the same shell resultants M11, M22, V13, S11 and S22. Maximum displacements were 0.008, 0.026, and 0.026 mm for Types 1, 2, and 3, respectively. For all models, the flexural demand was controlled by the transverse bending resultant M22, which peaked at 6.225, 3.216 and 2.818 kN·m/m for the three models respectively, while the longitudinal bending resultant M11 was smaller with a peak of 0.948, 0.664 and 0.651 kN·m/m respectively. Reinforcement verification was therefore carried out in each direction: M22 (Principal Transverse Reinforcement) and M11 (Longitudinal/Distribution Reinforcement). According to the baseline SNI 2847:2019 check, for the analysed 200 mm lining the minimum reinforcement, and not flexural strength demand, is the key factor determining the steel quantity needed in practice. The results show that a measurable redistribution of shell actions occurs based on geometry. The numerical values are not a benchmark solution as a formal study of mesh convergence is not included.

Keywords: Trapezoidal Channel, Finite Element Method, Irrigation, Structural Capacity, Reinforcement

P-ISSN: [2301-8437](#)
E-ISSN: [2623-1085](#)

ARTICLE HISTORY

Accepted:
8 April 2026
Revision:
25 September 2026
Published:
30 September 2026

ARTICLE DOI:
[10.21009/jpensil.v15i3.67041](#)



Jurnal Pensil :
Pendidikan Teknik
Sipil is licensed under a
[Creative Commons
Attribution-ShareAlike
4.0 International License](#)
(CC BY-SA 4.0).

Introduction

Reliable conveyance of irrigation water is essential for agricultural production to make water available to the irrigated areas at the right discharge and elevation. In Indonesia, irrigation networks are especially crucial for national food security, as a major amount of rice production depends on scientifically controlled irrigation systems (Prihapsari et al., 2024). Within an irrigation network, primary, secondary, tertiary and quaternary canals convey water from an intake or diversion structure to cultivated areas; the primary canal has the largest delivery function and therefore requires adequate hydraulic capacity, structural safety, and serviceability (Masloman, 2009; Novi & Vitianingsih, 2019).

Trapezoidal channels are widely used because they are hydraulically efficient, constructible and compatible with earthworks. Nevertheless, their conventional design may lead to excessive material use when geometric dimensions, lining thickness and reinforcement spacing are not optimized. Previous studies have shown that seepage, lining deterioration, and geometric parameters strongly influence canal performance, while concrete or geomembrane linings can substantially reduce water losses but may lose effectiveness with age and poor maintenance (Han et al., 2024).

From a structural perspective, reinforced-concrete channel linings behave as thin plate or slab-like elements supported by soil and subjected to combined actions from self-weight, water pressure, soil pressure, and operational loads. Numerical modelling is useful for identifying localized stress concentrations, deformation patterns, and likely serviceability problems that are difficult to observe using simplified hand calculations alone (Jiang et al., 2022; Roostrianawaty & Mahmudah, 2023). In canal structures, the junction between the floor slab and side wall is a critical transition zone, and similar stress-concentration concerns have been reported in open-channel and water-retaining structure analyses (Yiğit & Üstüner, 2024).

At a practical level, the primary canal in the Bunga Raya irrigation area, Siak Regency, Riau, has experienced disruptions in water distribution, thereby necessitating an economical design dimension to reduce damage and improve efficiency (Haris et al., 2016). Additional issues arise from the capacity of reinforced concrete canal structures related to reinforcement detailing, which affects the self-weight of the structure. This condition presents a challenge regarding the potential for structural failure due to existing soil conditions. Research by Elshaarawy & Elmasry (2024) indicates that increasing the thickness of trapezoidal canal lining layers has a significant effect on structural failure caused by water seepage. These observations indicate that the structural performance of a concrete-lined channel cannot be assessed from its dimensions alone; lining properties and reinforcement details also affect the resulting response.

If the dimensions of the section are changed in the case of a reinforced-concrete canal lining, the stiffness of the lining is also changed, and the distribution of internal forces to be resisted by the reinforcement is also changed. Slab studies have demonstrated that the arrangement of reinforcement and the thickness of the members can affect the structural capacity and the material demand under a specific loading condition (Jia & Chiang, 2022). The same relationship is assumed to exist in trapezoidal canal sections, but the relationship between canal geometry and required reinforcement has not been studied directly.

This study thus examines the effect of the channel width in the upper section by comparing three trapezoidal channel shapes with the same bottom width, height, thickness of the channel lining, material characteristics, load definitions and support assumptions. Shell forces are internal forces per unit of in-plane length, and are reported as M11, M22 for directional bending, V13 for transverse shear, and S11, S22 for directional shell stress (Computers and Structures, Inc., 2016). Evaluation of the research question is quantitative based on (i) magnitude and location of the directional shell resultants; (ii) maximum displacement; and (iii) a flexural-capacity ratio based on a code, $\phi M_n / M_u$. This comparison is to see if a change in the upper width will result in a systematic

change in structural demand and if the same amount of reinforcement can be interpreted for all channel configurations.

Literature Review and Theoretical Framework

Structurally, the trapezoidal concrete lining can be modeled as shell components that are interconnected. The slope change at the floor-wall junction introduces a local change in stiffness and load transfer, which makes this area more susceptible to bending than the relatively uniform areas of the floor and wall, where internal water pressure pushes outwards on the wall, while self-weight, soil reaction and external pressure push inwards (Cheng et al., 2022). The force distribution that is created is thus dependent on the loading and the geometry. There is another influence, however, when the soil supporting the foundation is not uniformly stiff, which is the foundation restraint (Naqvi et al., 2025). Plate bending results M11, M22 are given in the shell local 1 and 2 directions and M12 as a twisting resultant, all of which are unit in-plane length results. There are many other measures of serviceability besides building-slab deflection ratio that should not be used for irrigation channels. For liquid containing and conveyance structures, there is a focus on respecting the liquid tightness, minimum cracking, durability in addition to deformation control. As a result displacement is then treated here as a comparative response parameter, and the minimums of reinforcement and the requirements for crack control are treated explicitly, but $L/360$ is not treated as a definitive acceptance criterion for the canal itself (Rodd & Castel, 2022; Way & Viljoen, 2023). Because irrigation canals remain in service under varying water levels, maintaining the intended geometry is also part of their long-term performance (Hosseinzadeh Asl et al., 2020).

Field studies have shown that canal seepage is strongly affected by lining condition, perimeter treatment, and defects developed during service (Al-adili et al., 2015). From a structural perspective, this is relevant because cracks formed in highly stressed regions may subsequently provide pathways for water loss (Lund et al., 2023). Seepage-related studies are therefore considered here to relate the locations of concentrated structural demand to the potential deterioration of hydraulic performance (Giroud & Plusquellec, 2022).

Modelled seepage through canal linings containing concrete cracks and geomembrane damage, and subsequent work quantified the equivalent hydraulic conductivity of cracked concrete linings (Han et al., 2021). Their results are relevant to the present structural analysis because a cracked lining no longer has the hydraulic characteristics assumed for an intact section. Locations subjected to concentrated structural demand therefore deserve attention not only from the viewpoint of reinforcement design but also because cracking at these locations may influence water loss.

A measurable increase in seepage when cracking was introduced into a rigid canal liner. Seepage itself is not included in the present FEM model; nevertheless, their result gives additional practical importance to the location of maximum structural demand. If cracking develops repeatedly at the floor-wall junction, the consequence may extend beyond local structural damage to deterioration of the canal's conveyance performance (El-Molla & Eltarabily, 2023).

The feasibility of the finite-element results relies on the ability to take the directionally specified shell moments and convert these to a uniform basis for reinforcement design. It is thus critical that the shell local-axis definition be taken into account: M11 for reinforcement in the local-1/longitudinal direction, M22 for reinforcement in the local-2/transverse cross-sectional direction. M12 is not a principal directional bending moment and cannot be used in place of a bending moment in a one way strip flexural check. Both M11 and M22 are still checked but the governing reinforcement direction is determined by the orientation of the physical shell and not an arbitrary contour magnitude (Suárez & Gálvez, 2026).

The flexural strength is measured according to the SNI 2847:2019 for the practical reinforcement check and the reinforcement minimum will be checked separately. For deformed bars having $f_y < 420$ MPa, the minimum reinforcement ratio according to SNI 2847:2019 Table

24.4.3.2 is 0.0020 (for both shrinkage and temperature reinforcement). This is a critical minimum requirement for the existing thin channel lining as it can be controlling even when the required steel area based on the FEM moment is small. For liquid-carrying structures, the detailing generated must also be reviewed to ensure it is crack free and will be liquid-tight (Badan Standardisasi Nasional, 2019).

Research Methods

ETABS with four-node shell elements were used for finite element analyses. The three channel models provided in the document were lined with a 200 mm thick reinforced-concrete lining. These material values for the FEM model were used: 18.68 MPa for the concrete compressive strength (f_c'), 20,313.57 MPa for the concrete elastic modulus (E), 0.20 for the Poisson ratio, and 23,544 kN/m³ for the concrete mass density (γ). The reinforcement verification was carried out with $f_y = 240$ MPa and nominal cover for concrete = 75 mm. For all three configurations a nominal shell discretization of around 0.50 m was employed throughout. The common discretization makes it easy to compare models, but a formal mesh-convergence analysis is not provided and may be considered as a limitation in the quantitative results.

The base slab was idealised by setting the degrees of freedom of translations at the base nodes to zero (restrained). This is not an actual soil-spring model, but a simplified support condition. Lateral pressure from the inclined walls and normal (hydrostatic) pressure on the wetted surfaces on the inside of the walls. For Types 1–3 the restraints, the shell local-axis convention, and the restraints where the loads were applied were kept the same (Chen et al., 2025). The adopted boundary condition idealization is summarized in Figure 4. The local shell axes were checked regularly to ensure that the analysis of the principal cross-sectional reinforcement check was carried out with bending action along axis M11 (Longitudinal or Local 1) and bending action along axis M22 (Transverse or Local 2).

The actual density of concrete was set and was used to calculate the self-weight. The maintenance live load was 1.92 kN/m². The last hydrostatic pressure applied in the model was 30.411 kN/m² while the total recorded lateral soil action was 12.996 kN/m² where the internal friction angle was 15.45°, cohesion was 11.767 kN/m² and the soil unit weight was 16.562 kN/m³. Strength combinations were defined based on SNI 1727:2020 section 2.4 and SNI 2847:2019 section 5.3.1, and hydrostatic fluid action as F and lateral soil pressure as H, based on the additional requirements in section 5.3.7 and 5.3.8. For the three channel geometries the same load cases and factors were employed to ensure that the differences were due to the geometry and not to variations in the definition of the loading (Badan Standardisasi Nasional, 2020).

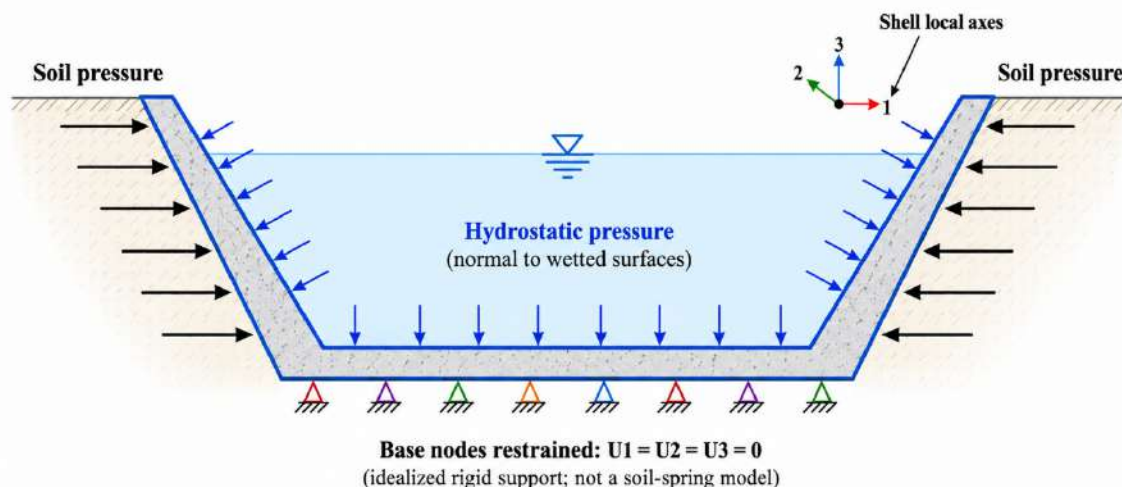


Figure 1. Boundary Conditions Idealization Model

All the three configurations were taken with the following material properties, nominal mesh size, local-axis convention, load definitions and boundary conditions to assess numerical consistency. Comparison is based on all the measured directional response quantities M11, M22, V13, S11, S22, and maximum displacement. As a formal mesh-sensitivity series is not provided, this study does not assert mesh-independent benchmark values, but it serves for a controlled comparative assessment, as well as for the code-based verification of reinforcement at the governing locations.

Three trapezoidal primary irrigation-channel sections were modelled with reinforced concrete material properties. The structural model used a concrete thickness of 200 mm 100 mm, compressive strength f_c' of 14.53 MPa, elastic modulus of 17,915.57 MPa, and unit weight of 23,544 kN/m³. As a controlled geometric comparison, three primary irrigation channel configurations in the form of trapezoids were analysed. All the models had a bottom width of 6.0 m and a height of the wall of 3.1 m and the top width was made 11.0 m for Type 1 and 9.0 m for Type 2 and 15.0 m for Type 3. The thickness of the lining, properties of the lining material, loads, assumptions and the nominal discretization remained constant. The three cross-sections are illustrated in figures 1, 2 and 3. This setup removes the interaction between the upper width and subsequent splay of the side walls in terms of load transfer, bending demand, and deformability. These geometries represent progressively reduced sections and therefore allow comparison of the relationship between dimensional reduction, serviceability response, and reinforcement demand (Q. Li et al., 2022).

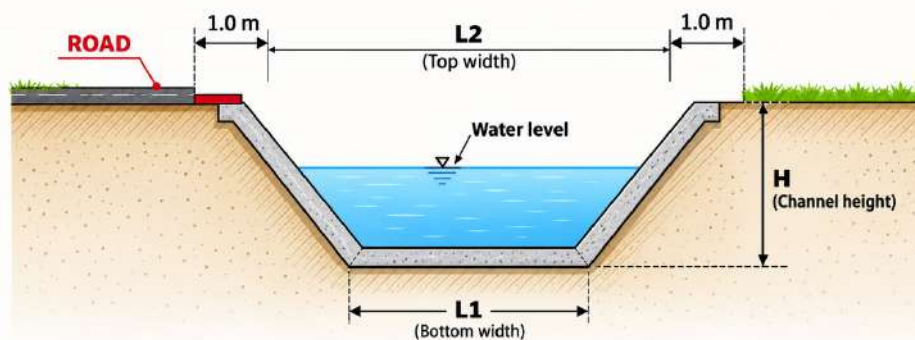


Figure 2. Primary Irrigation Channel Section Plan

None of the three models is an independent channel section, since the only variable being investigated is the upper width. This one-dimensional geometric change is then compared to see how it affects the bending, stress, and displacement in the shell. It is not taken for granted that the greater overall width will result in a greater deformation since the overall width also influences the flow of the load through the floor-wall connection, which involves the presence of hydrostatic and soil pressures, the inclination of the walls and the manner in which they act together. Structural assessment included evaluations based on direction bend moments, shear in the transverse direction, stresses in the shell structure and maximum displacement. The strength check is a requirement that $\phi M_n \geq M_u$. Serviceability is discussed using the concepts of the magnitude of the displacement and the implications for crack control, and not simply the $L/360$ as a code limit for a canal. Principal transverse direction is selected for reinforcement design as the local axis 2 is parallel to the direction of the cross-section bending, M11 is checked independently for the longitudinal/distribution direction. The following is a brief interpretation of the ETABS shell-resultant definitions.

The flexural reinforcement was checked per m width of lining. Based on the capacity check, the design was used with $h = 200$ mm, clear cover = 75 mm, and D10 bars, while the effective

depth d was taken as 120 mm, the flexural reduction factor is taken as $\varphi = 0.80$ based on SNI 2847:2019 Section 21.2. The required strength of steel area was determined by $M_u = \varphi A_s f_y (d - a/2)$; where $a = A_s f_y / (0.85 f_c' b)$. The code minimum for deformed bars with $f_y < 420$ MPa is $\rho_{min} = 0.0020$; for a 1,000-mm strip and $h = 200$ mm this gives $A_{s,min} = 400 \text{ mm}^2/\text{m}$. The area of the baseline reinforcement check was $448.8 \text{ mm}^2/\text{m}$ for D10-175 mm. End details are always subject to requirements for crack-control, joints and durability in a structure conveying the liquid.

Research Results and Discussion

Stress-strain distribution

The FEM contours indicate that the highest variations of bending and stress are found in the area of the floor-wall transition (where the shell orientation changes), and load transfer between the base and inclined wall is localized. Figure 3–17 show the respective figures for each type, which are viewed in the same way. The maximum and minimum are briefly summarized in Table 1; a comparison of the numbers without using the colour of the contours is thus possible. The results are reported in a uniform manner for the same components across all three models and the ambiguity of comparing different resultants across channel types is eliminated (Xin, 2012).

In the flexural check, M_u is the shell moment demand in the direction of the shell (factored per metre width), M_n is the nominal flexural resistance, and φ is the appropriate strength-reduction factor. The Governing M22 direction's capacity ratio $\varphi M_n/M_u$ is reported. M11 is evaluated separately in the orthogonal direction; shear transfer/stress concentration in the shell (V13, S11/S22) is not evaluated as an alternative to the directional flexural moments. The directionally response is systematically different for the three geometries. There is a large M22 demand for Type 1 ($6.225 \text{ kN}\cdot\text{m}/\text{m}$) and a large S22 stress for this Type (0.99 MPa), while the smaller M22 values of 3.216 and $2.818 \text{ kN}\cdot\text{m}/\text{m}$ are observed for Types 2 and 3, respectively. M11 is consistently lower than M22: 0.948, 0.664, and $0.651 \text{ kN}\cdot\text{m}/\text{m}$ for Types 1–3. This will verify that the bending stress that is the principal in the adopted bending axis is transverse to the channel axis. So the governing reinforcement calculation is then for M22 and M11 is applicable to the longitudinal/distribution reinforcement. The greatest demand is concentrated in the vicinity of the floor-wall junction, which can be taken up selectively and detains in the area of cracks can be secured. All three configurations have the same components as responses presented in Table 1.

Table 1. Coherent FEM response components for three channel types

Type	Upper Width (m)	Displacement (mm)	M11 Max (kN.m/m)	M22 Max (kN.m/m)	V13 Max (kN/m)	S11 Max (MPa)	S22 Max (MPa)
1	11	0.008	0.948	6.225	0.057	0.18	0.99
2	9	0.026	0.664	3.216	0.038	0.11	0.51
3	15	0.026	0.651	2.818	0.042	0.08	0.48

The resultants are the same for all three channel types and the response table is based on the current model outputs. A formal mesh-convergence series is not included and therefore the reported extrema are results of a consistent comparative mesh and should not be interpreted as being mesh-independent.

The largest local response is found at the intersection of the floor slab and inclined wall, close to the intersection. This is mechanistically similar to the sudden shift in orientation and rotational constraint of the shells. The maxima are thus to be understood as local requirements rather than as values over the whole lining. The overlap of the critical area over Types 1, 2 & 3 also shows that the geometry affects the amount of response but does not affect the fundamental floor-wall load transfer mechanism (Mo & Lou, 2020).

The maximum displacement occurred in Type 1 as 0.008 mm and in both Type 2 and 3 as 0.026 mm. The values are small compared to the thickness of lining (200 mm) but are not proportional to upper width. $L/360$ values that are not stipulated as “passing” the $L/360$ requirement were not found for a canal-specific rationale of the application of $L/360$ to the present soil-supported liquid-conveying lining. Rather, they are employed to analyze comparative deformation behavior of the three models, with serviceability interpretation relating to crack control, durability and liquid-tightness considerations (ACI Committee 350, 2021) .

Type 1 had the greatest M22 moment and S22 stress but at the same time had the least recorded maximum displacement (0.008 mm), while Types 2 and 3 had a similar recorded maximum displacement of 0.026 mm, but the upper width of Type 3 is significantly larger than that of Type 2 (15 m and 9 m). The combination suggests that the length of the load transfer mechanism influences the type of requirement for the two parts of the mechanism: displacement demand is controlled by the wall inclination and geometry; the M22 demand is concentrated at the floor-wall transition. The results shown in Figure 18 and 19 are therefore plotted on separate axes and displacement is plotted on the left-hand axis and the governing M22 moment is plotted on the right, they are not to be interpreted as specifically correlated (Azam et al., 2024; Husainy, Zainuddin; Sucitra, 2023).

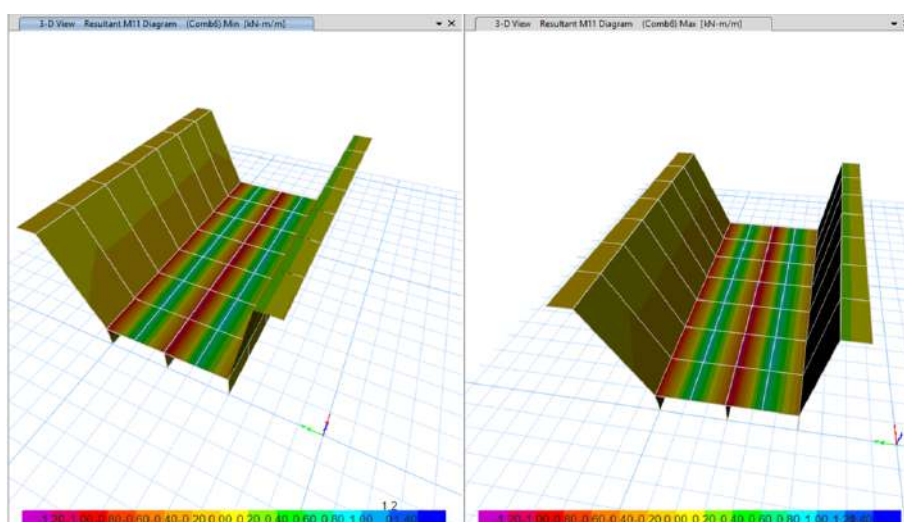


Figure 3. Resultan M11 Maximum and Minimum Diagram of Type 1 Primary Irrigation Channel

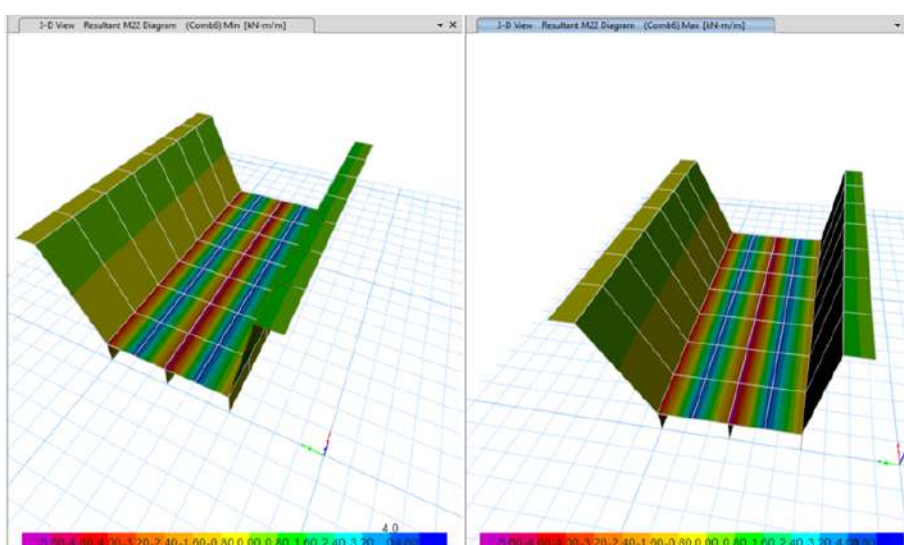


Figure 4. Resultan M22 Maximum and Minimum Diagram of Type 1 Primary Irrigation Channel

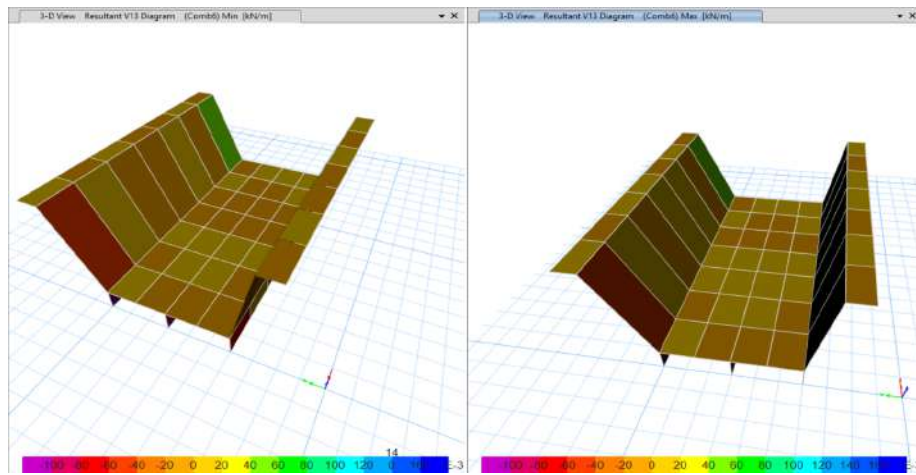


Figure 5. Resultan V13 Maximum and Minimum Diagram of Type 1 Primary Irrigation Channel

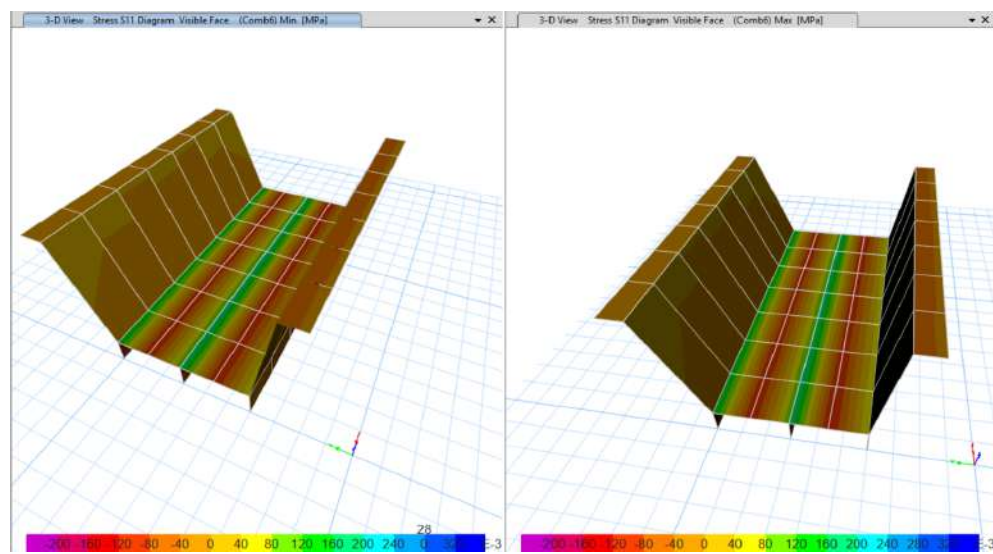


Figure 6. Resultan S11 Maximum and Minimum Diagram of Type 1 Primary Irrigation Channel

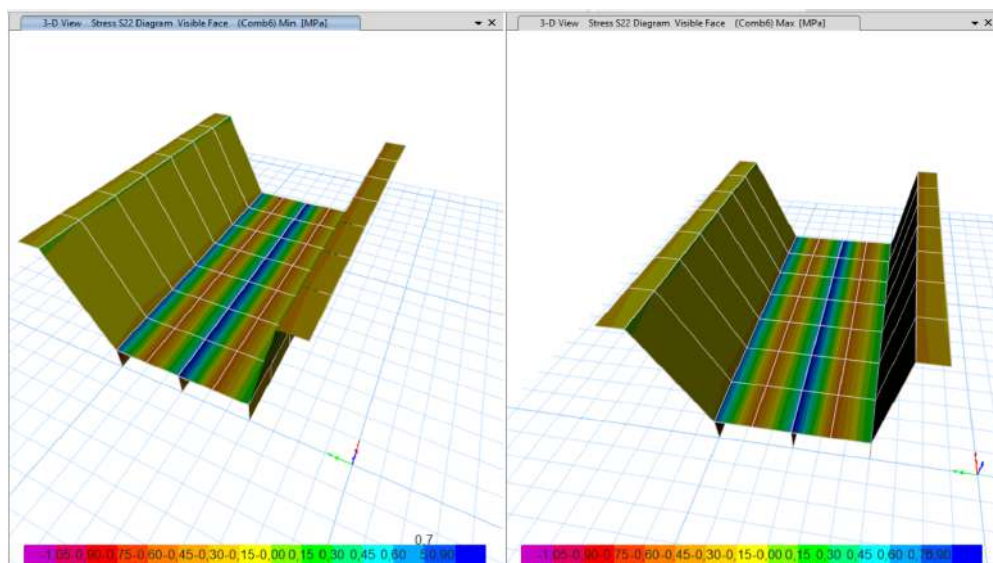


Figure 7. Resultan S22 Maximum and Minimum Diagram of Type 1 Primary Irrigation Channel

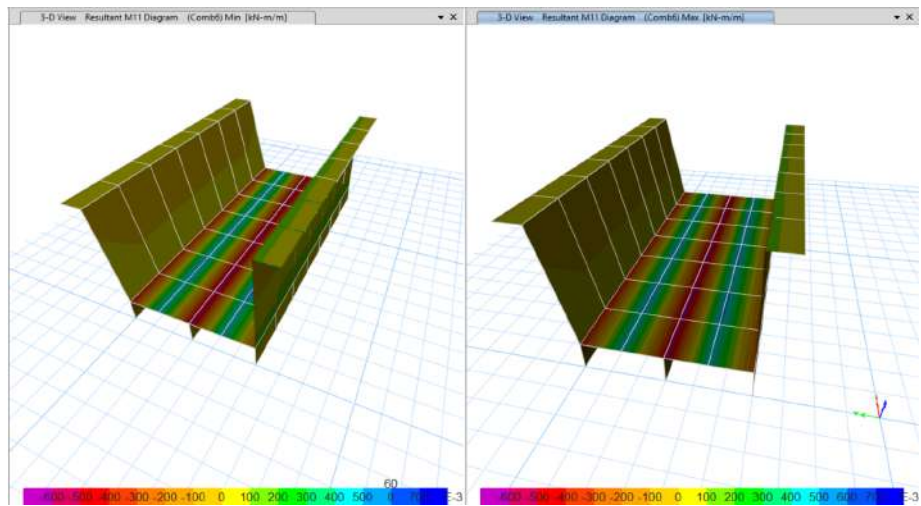


Figure 8. Resultan M11 Maximum and Minimum Diagram of Type 2 Primary Irrigation Channel

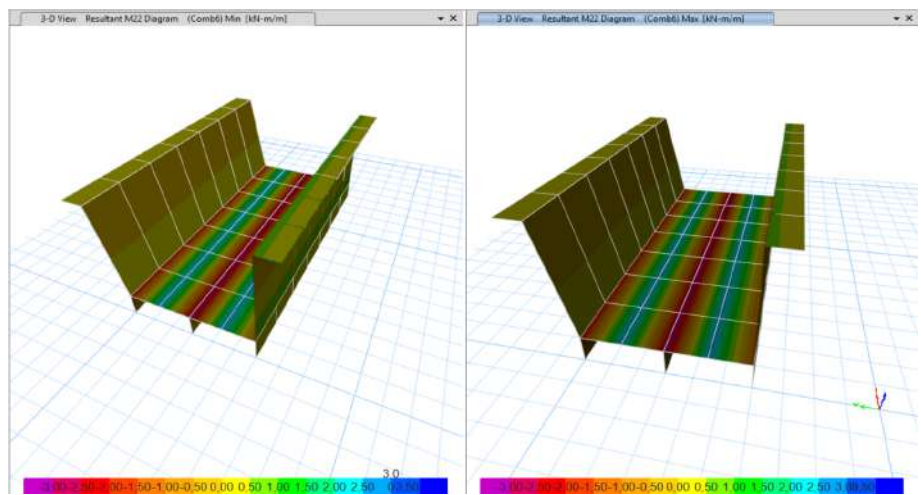


Figure 9. Resultan M22 Maximum and Minimum Diagram of Type 2 Primary Irrigation Channel

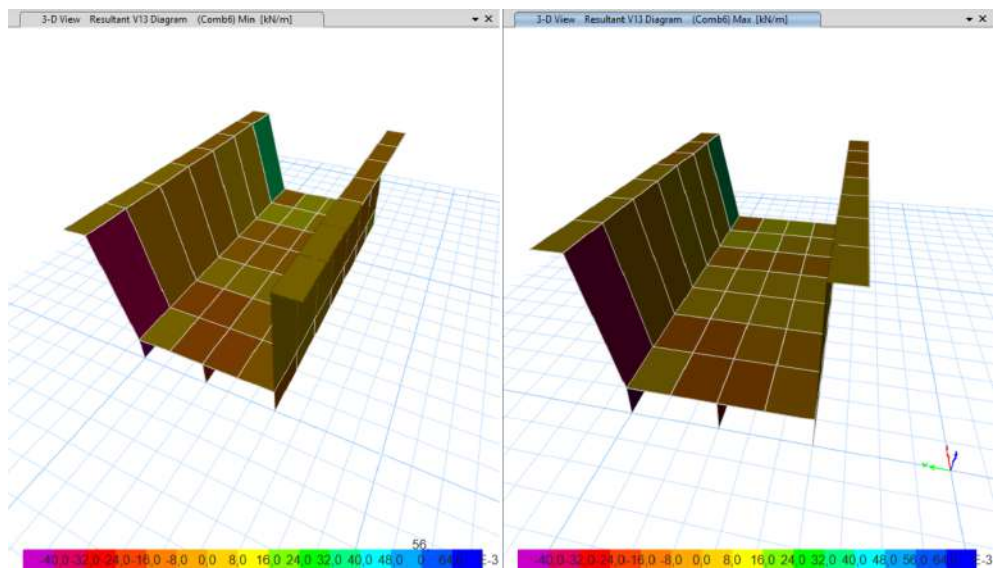


Figure 10. Resultan V13 Maximum and Minimum Diagram of Type 2 Primary Irrigation Channel

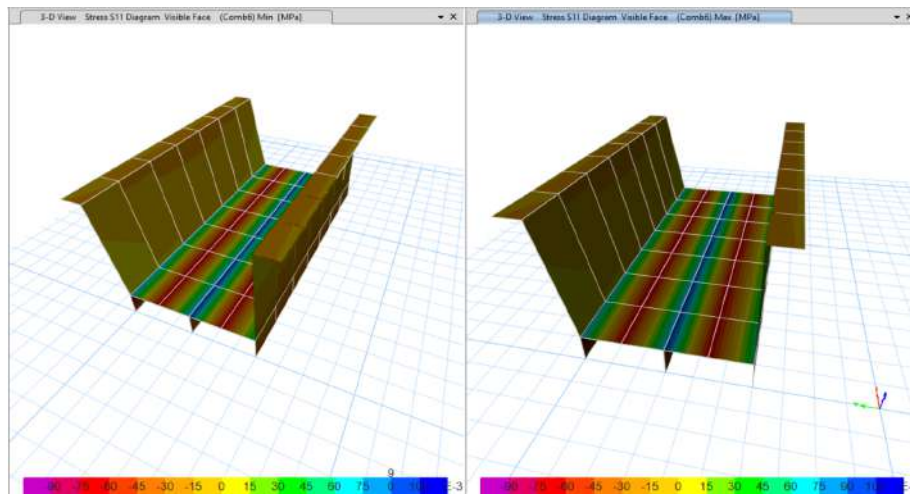


Figure 11. Resultan S11 Maximum and Minimum Diagram of Type 2 Primary Irrigation Channel

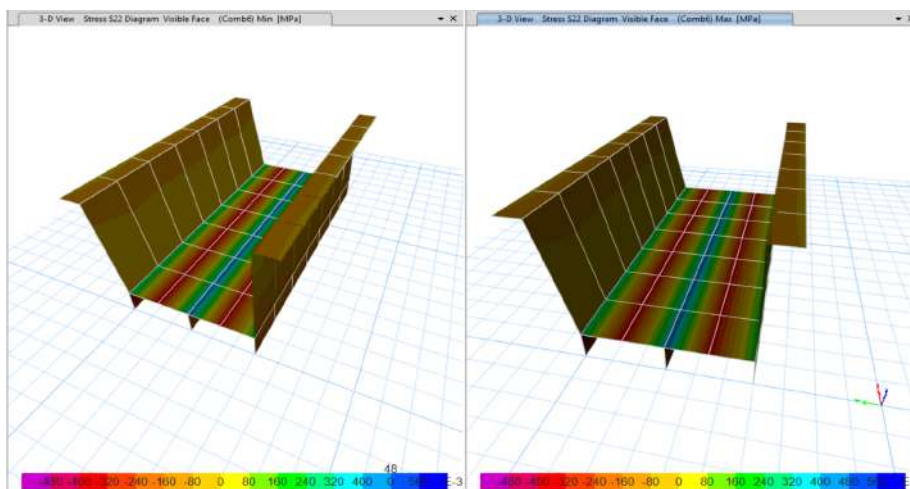


Figure 12. Resultan S22 Maximum and Minimum Diagram of Type 2 Primary Irrigation Channel

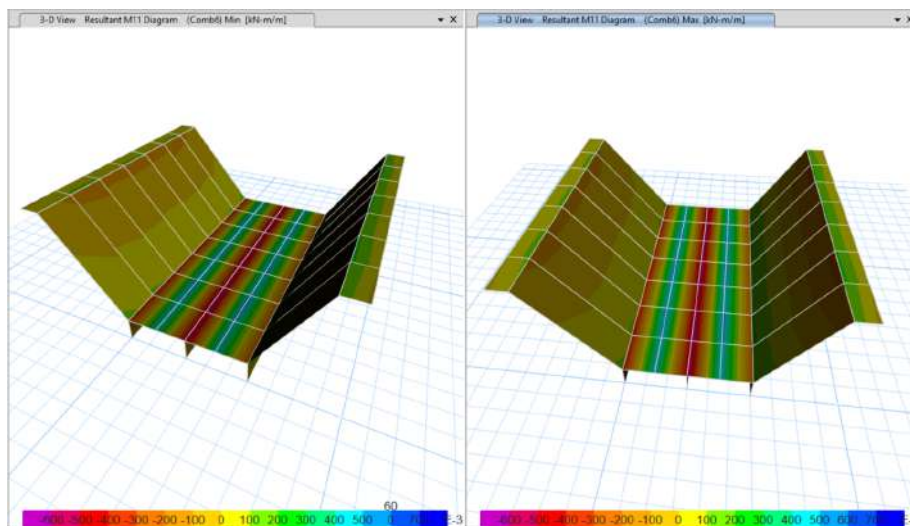


Figure 13. Resultan M11 Maximum and Minimum Diagram of Type 3 Primary Irrigation Channel

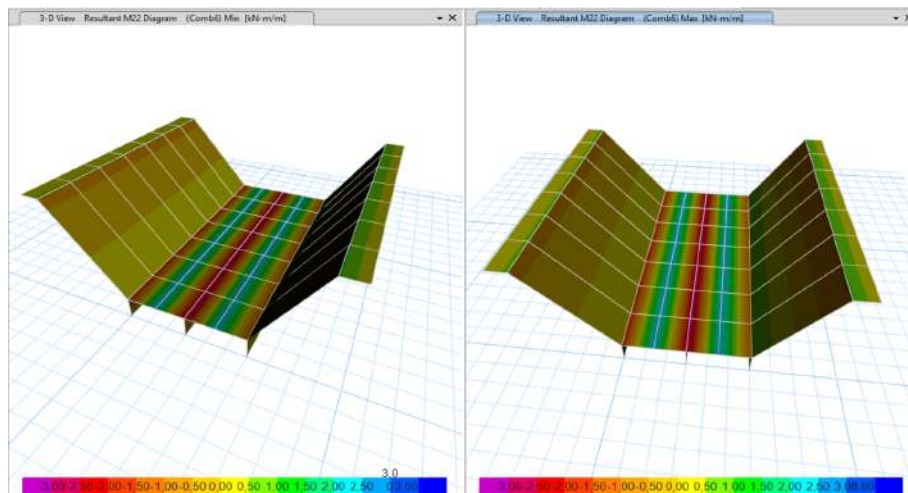


Figure 14. Resultan M22 Maximum and Minimum Diagram of Type 3 Primary Irrigation Channel

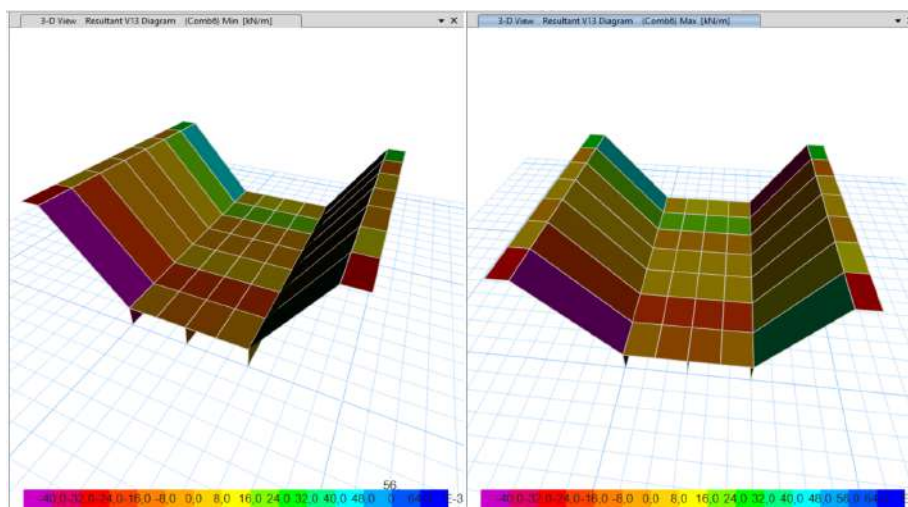


Figure 15. Resultan V13 Maximum and Minimum Diagram of Type 3 Primary Irrigation Channel

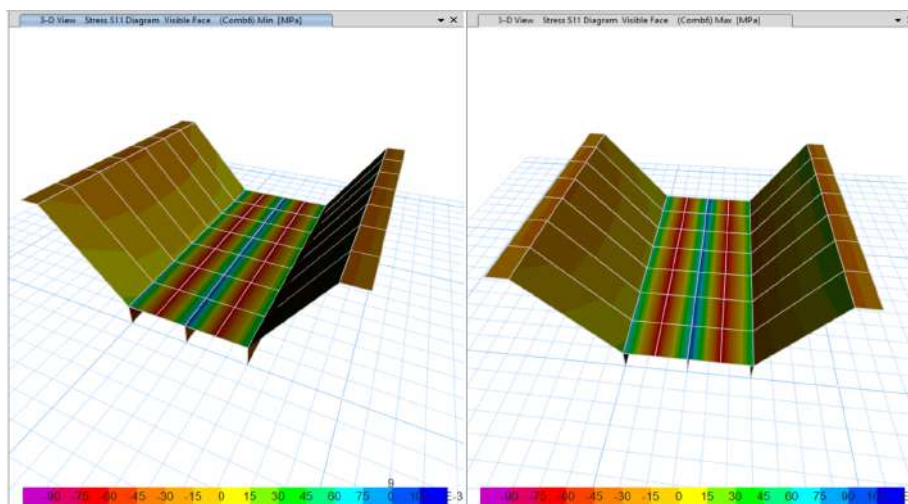


Figure 16. Resultan S11 Maximum and Minimum Diagram of Type 3 Primary Irrigation Channel

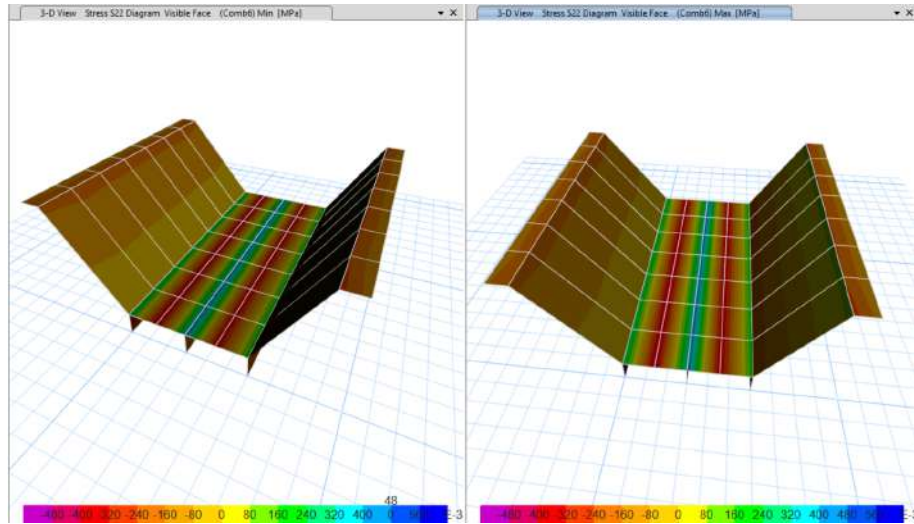


Figure 17. Resultan S22 Maximum and Minimum Diagram of Type 3 Primary Irrigation Channel

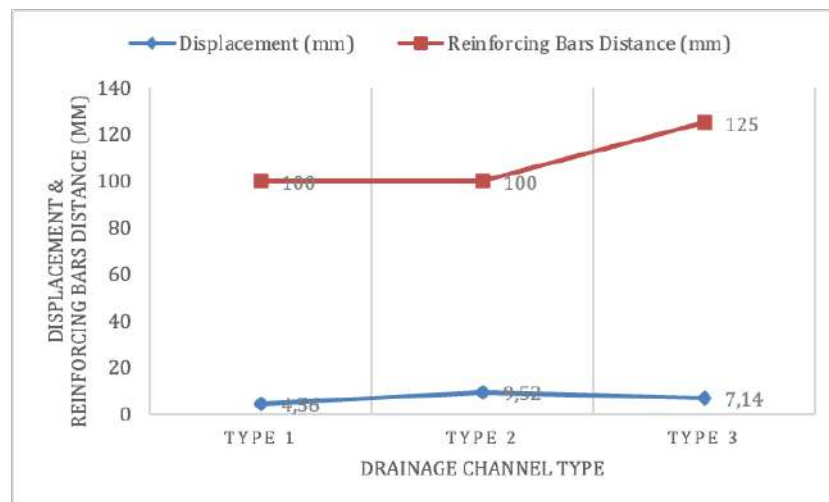


Figure 18. Displacement and Reinforcement Distance of Drainage Channel

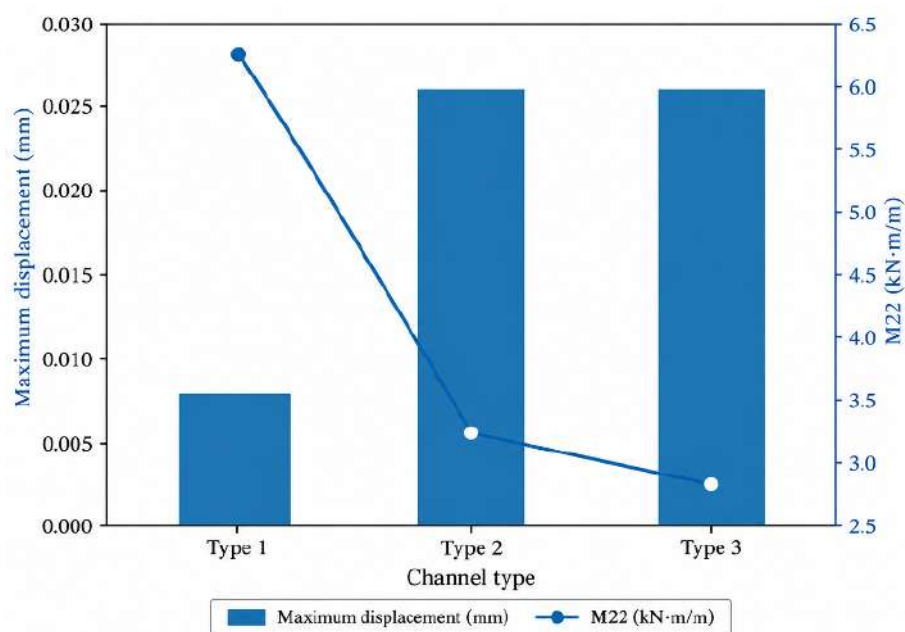


Figure 19. Maximum Displacement and M22 of Drainage Channel

Reinforcement demand

The bending resultants (M11 and M22) were calculated for both to assess the direction of reinforcement requirement. The M22 model runs the models using the same shell local-axis convention adopted by the ETABS models, with M22 indicating bending in the transverse direction of the channel cross-section, and M11 indicating bending in the longitudinal direction of the channel cross-section. This is because the resultant from the M22 yielded the highest bending demand for all three channel models, thus it was used in the transverse flexural-reinforcement calculation. The maximum M22 values were 6.225, 3.216, and 2.818 kN·m/m for Types 1, 2, and 3, respectively. The reinforcement requirements were calculated as nearly 329.13 mm²/m for Type 1 and 2; and 218.75 mm²/m for Type 2 and 3 respectively, using the reinforcement design parameters provided in the calculation sheet, which are: $f'_c = 24.9$ MPa, $f_y = 240$ MPa, $b = 1000$ mm, $h = 200$ mm, $d = 125$ mm, and $\varphi = 0.80$. These needs were calculated and the reinforcement provided in the transverse direction was Ø6-150 mm (Type 1) and Ø6-250 mm (Type 2 & 3). The results have shown that the reinforcing requirement varies depending on the geometry of the channel, with the highest reinforcement density for Type 1 as it produces the highest bending moment M22. The orthogonal bending component (M11) was also analysed, but was found to be smaller than M22 for all three channel configurations.

Table 2. Flexural reinforcement check using the governing M22 moment

Type	Mu =M22 (kN.m/m)	As _{perlu} (mm ² /m)	Provided
1	6.225	329.132	Ø6-150
2	3.216	218.75	Ø6-250
3	2.818	218.75	Ø6-250

The reinforcement result makes it more clear which role Geometry plays in the design process. The upper-width variation alters direction demand of the shell, while the steel quantity of the baseline is determined by the code minimum demand of the adopted low strength steel reinforcement and 200 mm lining. As a result, the FEM model is most useful to determine the direction of the dominant reinforcement and local areas that need to be addressed with anchorage and cracking, especially the junction of the floor and wall (Hervé-Secourgeon et al., 2021; Keintjem et al., 2025). Where reinforcement is deemed to be standardised then this may still be appropriate for construction, but only because it is deemed to meet the minimum reinforcement requirement of the governing standard and confirmed using the local M11/M22 demand, not just because of the channel size. The area of interface between the floor and the wall should be given special consideration from the point of view of durability, since it is appropriate that all concrete buildings carrying liquids should be susceptible to cracking and leakage (Rady, 2024). ACI 350 calls for more conservative serviceability criteria than for standard building components, such as liquid-tightness and crack limits. The present linear-elastic shell model does not model the crack width, seepage, bond between reinforcement and concrete, or nonlinear soil response; hence the presented stress and moment contours should not be used for predicting seepage but to determine critical areas for attention to detailing. Future work should incorporate the use of nonlinear cracked section, soil springs, hydraulic seepage and field monitoring.

If the section is cast in stages, the lower junction should receive special treatment to maintain continuity. Water stops or joint sealants may be required where construction joints coincide with potential seepage paths. For Indonesian irrigation infrastructure, the study offers a practical method for improving the structural design of primary channels (Basukala et al., 2024). Many irrigation rehabilitation projects use standard sections and standard reinforcement details. Standardization is useful for construction management, but it may lead either to overdesign or under-recognition of local critical zones (X. Li et al., 2024). The present study shows that even three similar trapezoidal sections require different interpretations (Roszevák & Haris, 2024). A

more rational design procedure would combine standard detailing with numerical verification for representative sections.

The research also supports the broader agenda of infrastructure sustainability. Reducing unnecessary reinforcement lowers embodied material consumption and construction cost. At the same time, strengthening the critical junction improves serviceability and may reduce long-term maintenance (Mergos, 2024). In irrigation systems, these two objectives are linked: a structurally reliable lining preserves hydraulic capacity, reduces water loss, and supports agricultural productivity (Lund et al., 2023). The main drawback of the numerical results is that there is no formal mesh convergence study. All the configurations were computed using the same nominal mesh, load definitions, material properties and support assumptions, but no mesh independence of the extrema was established. The study thus confirms that a controlled comparison between all the three width variants of the upper and the code-based reinforcement check is possible, but the absolute FEM extrema should not be considered as benchmark values. To support the additional verification with refined meshes, optionally independent analytical strip or field measurement is suggested (Gilbert, 2011).

Future work should measure the degree of mesh sensitivity with at least three different systematic refinements of the meshes used by the shell and report the change of M11 and M22. Other parameters considered should be soil stiffness, water depth, lining thickness, concrete strength and construction joint location (Peramuna et al., 2024). Of course, for serviceability verification, the modelling of crack width and measurements of seepage are of particular relevance, since for the case of irrigation channels the critical performance parameter is not a general deflection ratio for a building slab but liquid-tightness (Ravasini et al., 2023).

Conclusion

The global deformation and local directional shell demand vary as a result of the variation of the width of the upper side of the trapezoidal channel in the controlled FEM comparison, both quantities vary. The maximum displacement was found to be 0.008 mm for Type 1 and 0.026 mm for Types 2 and 3. The resulting transverse bending moment M22 was 6.225, 3.216, and 2.818 kN·m/m for each of the Types 1, 2, and 3, respectively, and greater than M11 in all the models. In that regard, M22 should be used as the basis for the principal flexural check made in the transverse mode, and M11 is left for the orthogonal flexural mode, in the longitudinal/distribution direction; use of M12 should not be considered a substitute for either of the two flexural modes. The greatest demand is clustered in the vicinity of floor-wall junction. The three types all have lower strength required area of steel, using a flexural check that should be satisfied according to the strength of the steel, whereas, the baseline reinforcement is based on minimum/crack-control requirements. In all three configurations, flexural capacity is greater than the governing M22 requirement and the baseline $\varnothing 6 - 150$ mm with A_s of 188.5 mm²/m is greater than that required. These findings are only comparative, since the mesh convergence is still too coarse. The development of the model should be refined by including mesh refinement, non-linear crack analysis, deformable-soil support, and the assessment of serviceability for the liquid-tightness and crack control aspects.

References

- ACI Committee 350. (2021). *Code Requirements for Environmental Engineering Concrete Structures (ACI 250-20) and Commentary (ACI 350R-20)*. www.concrete.org
- Al-adili, A., Al-ameer, O. A., & Al-sharbaty, A. (2015). Experimental investigation of joint filling materials performance on preventing seepage in lined open concrete canal (laboratory and field model). *KSCE Journal of Civil Engineering*, 20, 1936–1947. <https://api.semanticscholar.org/CorpusID:255530583>

- Azam, R., Riaz, M. R., Shakeel, M., Farooq, M. U., & Arshad, M. A. (2024). Economical design strategies for reinforced concrete one-way slabs: a parametric approach considering material strength and rebar size. *Discover Civil Engineering*, 1(1). <https://doi.org/10.1007/s44290-024-00106-7>
- Badan Standardisasi Nasional. (2019). Persyaratan Beton Struktural untuk Bangunan Gedung. In *SNI 2847-2019* (Number 8).
- Badan Standardisasi Nasional. (2020). *SNI 1727-2020: Beban Desain Minimum dan Kriteria Terkait untuk Bangunan Gedung dan Struktur Lain*. Badan Standardisasi Nasional Republik Indonesia.
- Basukala, A. K., Eschenbach, A., & Rasche, L. (2024). Effect of irrigation canal conveyance efficiency enhancement on crop productivity under climate change in Nepal. *Environmental Monitoring and Assessment*, 196(12), 1282. <https://doi.org/10.1007/s10661-024-13405-4>
- Chen, J., Tian, Y., Zhang, H., & Shi, H. (2025). Study on optimization measures for water level fluctuation of large water conveyance aqueducts. *PLOS ONE*, 20(4), e0320397. <https://doi.org/10.1371/journal.pone.0320397>
- Cheng, Y., Song, Y., Liu, C., Wang, W., & Hu, X. (2022). Numerical Simulation Research on the Diversion Characteristics of a Trapezoidal Channel. *Water (Switzerland)*, 14(17). <https://doi.org/10.3390/w14172706>
- El-Molla, D. A., & Eltarabily, M. G. (2023). Estimation of seepage losses from cracked rigid canal liners using finite element modeling. *Journal of Applied Water Engineering and Research*, 12, 152–166. <https://api.semanticscholar.org/CorpusID:259838753>
- Elshaarawy, M. K., & Elmasry, N. H. (2024). *Experimental and Numerical Modeling of Seepage in Trapezoidal Channels*. 43–60. <https://doi.org/10.51526/kbes.2024.5.3.43-60>
- Gilbert, R. I. (2011). The Serviceability Limit States in Reinforced Concrete Design. *Procedia Engineering*, 14, 385–395. <https://doi.org/10.1016/j.proeng.2011.07.048>
- Giroud, J. P., & Plusquellec, H. (2022). Evaluation of concrete and geomembrane lining options for a canal in Egypt. *Geosynthetics International*. <https://api.semanticscholar.org/CorpusID:247257811>
- Han, X., Wang, X., Zhu, Y., & Huang, J. (2021). A fully coupled three-dimensional numerical model for estimating canal seepage with cracks and holes in canal lining damage. *Journal of Hydrology*, 597, 126094. <https://doi.org/10.1016/j.jhydrol.2021.126094>
- Han, X., Zhu, Y., Wang, X., Ye, M., & Huang, J. (2024). Numerical estimation of the equivalent hydraulic conductivity for canal concrete lining with cracks. *Journal of Hydrology*, 633(February). <https://doi.org/10.1016/j.jhydrol.2024.131050>
- Haris, T. V., Saleh, A., & Muthia, A. (2016). Perencanaan Dimensi Ekonomis Saluran Primer Daerah Irigasi Bunga Raya. *Jurnal Teknik Sipil Siklus*, 2(1), 47–57.
- Hervé-Secourgeon, G., Hervé-Secourgeon, E., Bottoni, M., Voldoire, F., Razafimbelo, M., Gatuingt, F., Oliver-Leblond, C., Honorio, T., Kameh, A., Habib, S., & Escoffier, F. (2021). On structural finite element modeling strategies and their influence on the optimization of final constructability of reinforced concrete structures. *Nuclear Engineering and Design*, 385, 111541. <https://doi.org/10.1016/j.nucengdes.2021.111541>
- Hosseinzadeh Asl, R., Salmasi, F., & Arvanaghi, H. (2020). Numerical investigation on geometric configurations affecting seepage from unlined earthen channels and the comparison with field measurements. *Engineering Applications of Computational Fluid Mechanics*, 14(1), 236–253. <https://doi.org/10.1080/19942060.2019.1706639>
- Husainy, Zainuddin;Sucitra, R. (2023). Tinjauan Ulang Perhitungan Penulangan Struktur Beton

- Bertulang pada Gedung Bank NTB Syariah menggunakan Metode SNI 2847-2019. *Hexagon Jurnal Teknik Dan Sains*, 4, 28–37.
- Jia, Y., & Chiang, J. C. L. (2022). Finite Element Analysis of Punching Shear of Reinforced Concrete Slab–Column Connections with Shear Reinforcement. In *Applied Sciences* (Vol. 12, Number 19, p. 9584). <https://doi.org/10.3390/app12199584>
- Jiang, H., Gong, J., Wang, Z., Li, L., Liu, Q., & Wang, Y. (2022). Analytical solution for the response of lined trapezoidal canals under soil frost action. *Applied Mathematical Modelling*, 107(23), 815–833. <https://doi.org/10.1016/j.apm.2022.03.016>
- Keintjem, M., Suwondo, R., & Suangga, M. (2025). Finite Element Based Optimization of Two-Way Concrete Slabs: A Comparative Study on Embodied Carbon and Cost Efficiency. *Engineering, Technology and Applied Science Research*, 15(4), 25251–25256. <https://doi.org/10.48084/etasr.11607>
- Lee, S. E., & Lee, D. M. (2023). Development of Numerical Modelling Techniques for a Firefighting Water Tank with an Anti-Wave Plate under Seismic Loads. *Applied Sciences (Switzerland)*, 13(21). <https://doi.org/10.3390/app132111689>
- Li, Q., Wu, B., & Zhou, H. (2022). Damage Simulation Analysis of Canal Concrete Lining Plates Based on Temperature-Stress-Water Load Coupling [Análisis de simulación de daños de placas de revestimiento de hormigón de canales basado en el acoplamiento temperatura-tensión-carga de agua]. *Sustainability (Switzerland)*, 14(15), 9202–9228.
- Li, X., Zhou, Z., Wang, B., & Huang, W. (2024). Study on impermeability of reinforced concrete wall with horizontal construction joints. *Construction and Building Materials*, 438, 137220. <https://doi.org/10.1016/j.conbuildmat.2024.137220>
- Lund, A. A. R., Gates, T. K., & Scalia, J. (2023). Characterization and control of irrigation canal seepage losses: A review and perspective focused on field data. *Agricultural Water Management*, 289, 108516. <https://doi.org/10.1016/j.agwat.2023.108516>
- Masloman, H. (2009). *Perencanaan Saluran Primer, Sekunder Dan Tertier Pada Daerah Irigasi Sita*. 9(1), 25–34.
- Mergos, P. E. (2024). Structural design of reinforced concrete frames for minimum amount of concrete or embodied carbon. *Energy and Buildings*, 318, 114505. <https://doi.org/10.1016/j.enbuild.2024.114505>
- Mo, T., & Lou, Z. (2020). Numerical Simulation of Frost Heave of Concrete Lining Trapezoidal Channel Under an Open System. *Water*. <https://api.semanticscholar.org/CorpusID:214545559>
- Naqvi, M. W., Sadiq, Md. F., Cetin, B., Uduebor, M., & Daniels, J. L. (2025). Engineered Water Repellency to mitigate Freeze Thaw Damages in Soils. *Cold Regions Science and Technology*. <https://api.semanticscholar.org/CorpusID:280210611>
- Novi, A. S., & Vitianingsih, A. V. (2019). WebMap Untuk Pengembangan Jalur Irigasi Baru di Kabupaten Lamongan. *J I M P - Jurnal Informatika Merdeka Pasuruan*, 4(1), 255–264. <https://doi.org/10.37438/jimp.v4i1.195>
- Peramuna, P. D. P. O., Neluwala, N. G. P. B., Wijesundara, K. K., Venkatesan, S., De Silva, S., & Dissanayake, P. B. R. (2024). Novel approach to the derivation of dam breach parameters in 2D hydrodynamic modeling of earthquake induced dam failures. *Science of The Total Environment*, 927, 171505. <https://doi.org/10.1016/j.scitotenv.2024.171505>
- Prihapsari, S. D., Utari, M., Rosadi, A. S. Z., Azaki, N., Fathurrochim, R. A., Azhari, N. F., & Nisaa, S. A. (2024). Informasi Statistik Infrastruktur PUPR 2023. In *Pusat Data dan Teknologi Determination of The Structural...* – 551
Costa, Anthony, et al.

Informasi PUPR. Kementerian Pekerjaan Umum dan Perumahan Rakyat.

- Rady, M. (2024). Application of evolutionary algorithms to design economic flat slab buildings based on the intended function. *Scientific Reports*, 14(1), 8826. <https://doi.org/10.1038/s41598-024-58763-8>
- Ravasini, S., Vecchi, F., Belletti, B., & Muttoni, A. (2023). Verification of deflections and cracking of RC flat slabs with numerical and analytical approaches. *Engineering Structures*, 284, 115926. <https://doi.org/10.1016/j.engstruct.2023.115926>
- Rodd, J., & Castel, A. (2022). Structural considerations to minimise the risk of horizontal cracks in the wall of circular concrete tanks. *Structures*, 40(May), 1091–1106. <https://doi.org/10.1016/j.istruc.2022.04.066>
- Roostrianawaty, N., & Mahmudah, R. (2023). Perencanaan Dimensi Saluran Irigasi Tersier Jepun Pada Daerah Irigasi Kebonagung Kabupaten Sumenep. *Prosiding SEMSINA*, 4(01), 276–283. <https://doi.org/10.36040/semsina.v4i01.8056>
- Roszevák, Z., & Haris, I. (2024). Finite Element Analyses of Cast-in-situ RC Flat Slab with an Equivalent Frame for Horizontal Loads. *Periodica Polytechnica Civil Engineering*, 68(1 SE-Research Article), 289–304. <https://doi.org/10.3311/PPci.21896>
- Selim, T., Elshaarawy, M. K., Elkiki, M., & Eltarabily, M. G. (2024). Estimating seepage losses from lined irrigation canals using nonlinear regression and artificial neural network models. *Applied Water Science*, 14(5), 90. <https://doi.org/10.1007/s13201-024-02142-1>
- Suárez, F., & Gálvez, J. C. (2026). Influence of steel–concrete bond degradation on punching shear in reinforced concrete: A detailed finite element analysis. *Engineering Fracture Mechanics*, 343, 112289. <https://doi.org/10.1016/j.engfracmech.2026.112289>
- Way, A. C., & Viljoen, C. (2023). Reliability performance in tension governed reinforced concrete reservoirs as a function of target crack width. *Structural Concrete*, 24(6), 7726–7741. <https://doi.org/10.1002/suco.202201159>
- Xin, Z. (2012). *Finite Element Numerical Simulation for Lining Channel Frost Heaving in Donggang Area*. <https://api.semanticscholar.org/CorpusID:113368114>
- Yiğit, M. E., & Üstüner, B. (2024). Investigation of the seismic response of irrigation channel using Coupled Eulerian-Lagrangian approach. *Challenge Journal of Concrete Research Letters*, 15(3), 90–100. <https://doi.org/10.20528/cjcr.2024.03.003>