STRUCTURAL ANALYSIS AND DESIGN VERIFICATION OF THE PROPOSED ALUMINUM–GLASS BALUSTRADE LOCATED AT , IN COMPLIANCE WITH ALUMINUM DESIGN STANDARD AS1664.1 AND GLASS DESIGN STANDARDS AS1288.

Introduction:

Engineering was contracted to conduct structural analysis and design verification of aluminum-glass balustrade element (post and railing) and fixing connection for the post to enable the issuance of certification (form 15) at , .

AUSTRALIAN STANDARDS

- AS 1170.0:2002 General Principles
- AS 1170.1:2002 Permanent, Imposed, and Other Actions
- AS/NZS 1170.2:2021 Wind Action
- AS 1170.4: 2007 Earthquake Action
- AS 1664.1: 1997 Aluminum Structure
- AS 1288-2006 - Glass in buildings - Selection and installation

REFERENCE DRAWINGS:

- Job: – BAL02 Sheet1 to Sheet 3; Rev. A; Set A; Dated:
- Job: – BAL04 Sheet1 to Sheet 3; Rev.A; Set B; Dated:
- Job: – BAL05 Sheet1 to Sheet 3; Rev.A; Set C; Dated:
- Job: – BAL02- Bracket Sheet1; Rev.A; Dated: .

PUBLIC PORTFOLIO SAMPLE ? CLIENT, SITE AND PROJECT IDENTIFIERS REDACTED

Material Properties (Client Preference):

6106 T6 Aluminum alloy		**11.52mm Clear Laminated Glass**	
Yield Stress,	Fty = 260 MPa	Density,	ρ = 2500 kg/m3
Tensile Stress,	Ftu = 240 MPa	Poisson's ration,	p = 0.22
Compression Stress,	Fcy = 172 MPa	Linear elastic modulus,	E = 70 GPa
Shear Stress,	Fsy = 96 MPa	Torsional elastic modulus,	G=28.7 GPa
Section Modulus,	E = 70 GPa	Surface Compression,	σ =69 MPa

ANALYSIS AND DISCUSSION:

This technical report delineates the structural assessment conducted for the Aluminum-Glass Balustrade and addresses client queries. The primary goal was to analyze the structural behaviour of the Aluminum-Glass Balustrade and its fixing connections for the Aluminum post, as illustrated below. Linear element models were employed for this analysis, emphasizing ascertaining structural capacities and ensuring compliance with serviceability requirements stipulated in AS 1664.1:1997 under specified limit states. The scope of the project is stipulated below:

1. Scope 1: Analysis of Balustrade 02 (BAL02) which Consists of:
    a. 75x30 Top Rail
    b. Double Webbed Australis Post
    c. One Way Australis Post
    d. Australis Half Post
    e. 2mm Thick Ali Sheet Flashing
    f. 11.52mm Thk Clear Laminated Glass Panel 1770mm High with a width of 1.10m, 0.785m and 0.95m

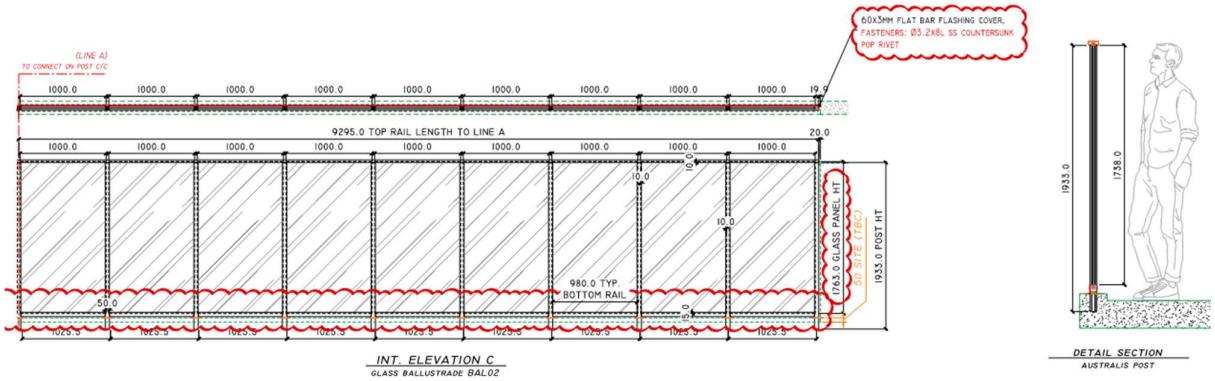


Figure 1. Aluminum-Glass Balustrade 02

2. Scope 1: Analysis of Balustrade 04 (BAL04) which Consists of:
    a. 75x30 Top Rail
    b. Double Webbed Australis Post.
    c. One Way Australis Post (End Post, Mid Rail and Bottom Rail).
    d. 11.52mm Thk Clear Laminated Glass Panel 910mm High with a width of 1050mm.
    e. Loose 60x60x6mm Angle Bar.

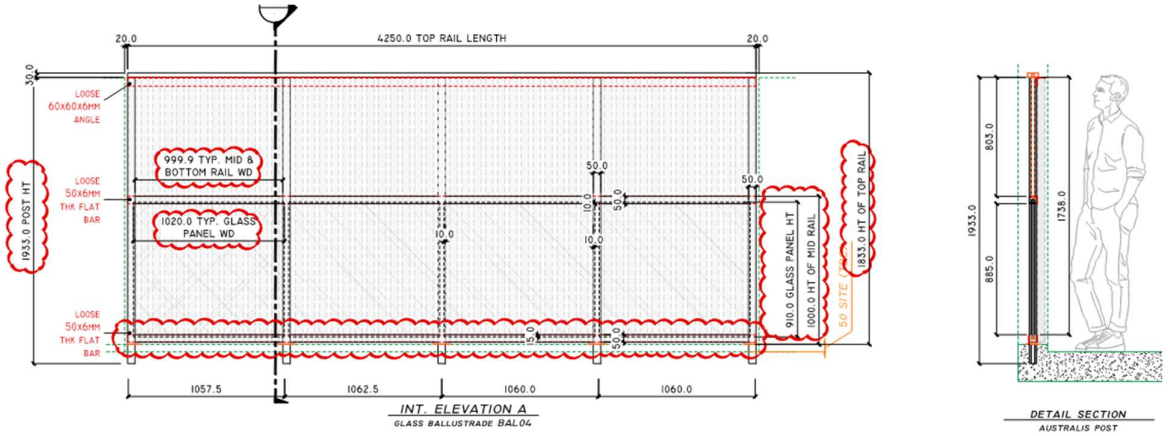


Figure 2. Aluminum-Glass Balustrade 04

2. Scope 1: Analysis of Balustrade 02 (BAL02) which Consists of:
    a. 75x30 Top Rail
    b. Double Webbed Australis Post
    c. One Way Australis Post
    d. Australis 90-deg Angle Two Way Post
    e. 11.52mm Thk Clear Laminated Glass Panel 2100mm High with a width of 900mm and 1200mm

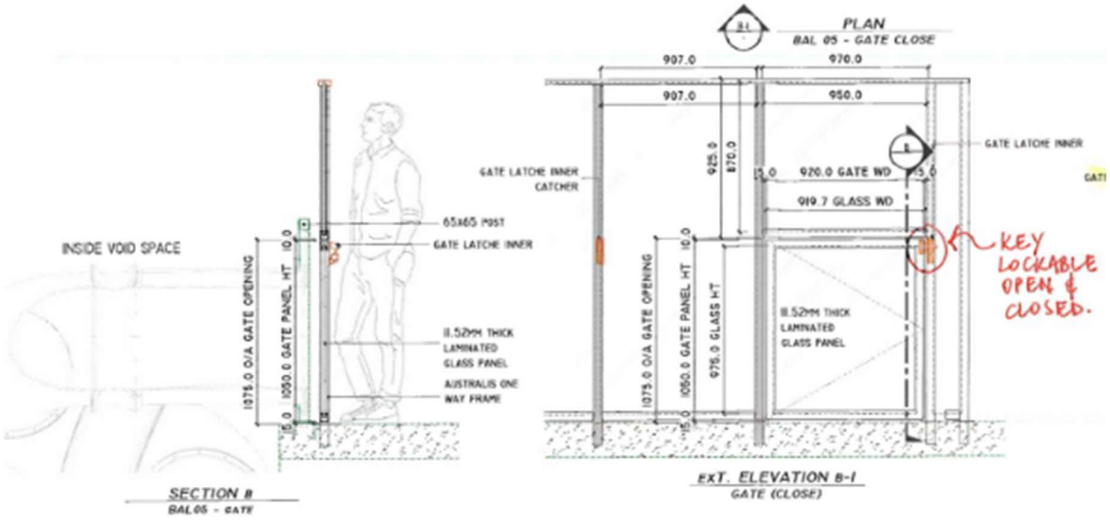


Figure 3. Aluminum-Glass Balustrade 05

The loadings under consideration encompass barrier action loadings following the stipulations of AS1288 Table J.1. Furthermore, the external wind pressure has been computed following the guidelines provided in AS1170.1. Additionally, seismic loads have been determined as per the design of parts and components section of AS1170.4:2007, employing the acceleration-based methodology. These comprehensive load assessments collectively inform the structural analysis.

The glass's load-bearing capacity is contingent upon the duration of the applied load, in accordance with the load duration factor specified in AS1288:2021 Table 3.3. In this analysis, the load duration under consideration comprises short-term conditions, applicable to seismic and wind loads (lasting ≤3 seconds), as well as medium-term conditions for imposed loads (lasting >3 seconds but <10 minutes). The calculation of external wind pressure accounts for 2.20 kPa, factoring in the external pressure coefficient for a balustrade positioned at the first level of the building. The Wind pressure Is the most Critical load case. This outcome supersedes the seismic loading effects, which is why the seismic results are not presented herein.

In the process of validating the integrity of the glass balustrade and its associated aluminium framing, we employ a two-fold approach. Firstly, we utilize linear analysis to assess the overall performance and load-bearing capacity of both glass and aluminium framing in a global context. Secondly, we employ finite element analysis to scrutinize the localized stress distribution along the surfaces of the glass and aluminium Bottom Track. We conduct assessments on varying glass widths, specifically 0.75 meters, 1.00 meters, and 1.20 meters. The objective is to ascertain the compliance of these diverse glass widths with Australian standards. Our certification process exclusively covers glass widths falling within the range of 0.75 meters to 1.20 meters. For glass widths beyond this range, we recommend undertaking a separate analysis for verification purposes. This systematic approach allows us to conduct a thorough evaluation of the structural robustness and functional performance of these elements.

SCOPE #1: ALUMINUM-GLASS BALUSTRADE 02

After conducting a series of calculations and evaluations to analyse the impacts of seismic, wind, and barrier loads on the aluminium balustrade, it was established that wind loading constitutes the most critical condition. The seismic load was quantified at 0.1 kN, and the wind load, dependent on the prevailing direction, varied between 0.044 to 0.055 kN/m. Nevertheless, the wind load, which amounted to 1.50 kPa, was the most significant factor.

Following an initial examination, it was apparent that the initial segments possess the necessary strength to endure seismic, barrier, and wind loads exerted on the balustrade. The maximum design capacity ratio (DCR) for the aluminum configuration stands at 0.869. The maximum DCR for each section used in Balustrade 02 is illustrated in Figure 04. As per the deflection criteria outlined in Table C1 of AS1170.0 for Handrail-post and rail systems, the deflection limit is determined as H/60 + Span/240, resulting in 66.88mm. Conversely, the global deflection is computed to be 44mm, indicating a safe value.

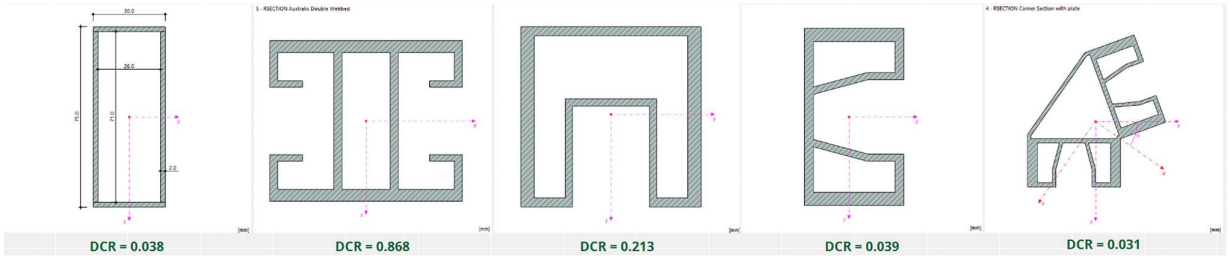


Figure 4. D/C Ratio by Section

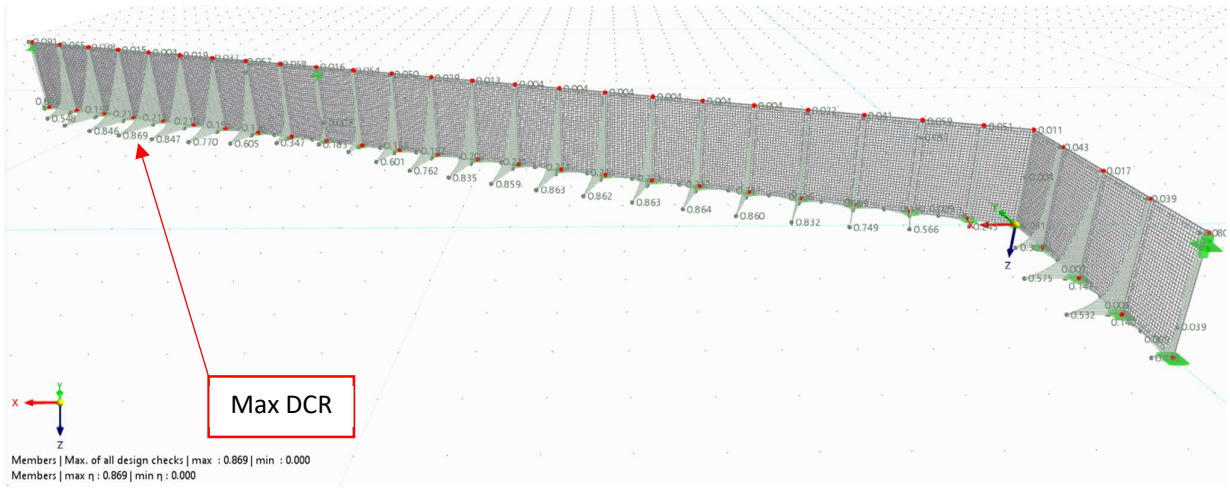


Figure 5. D/C Ratio

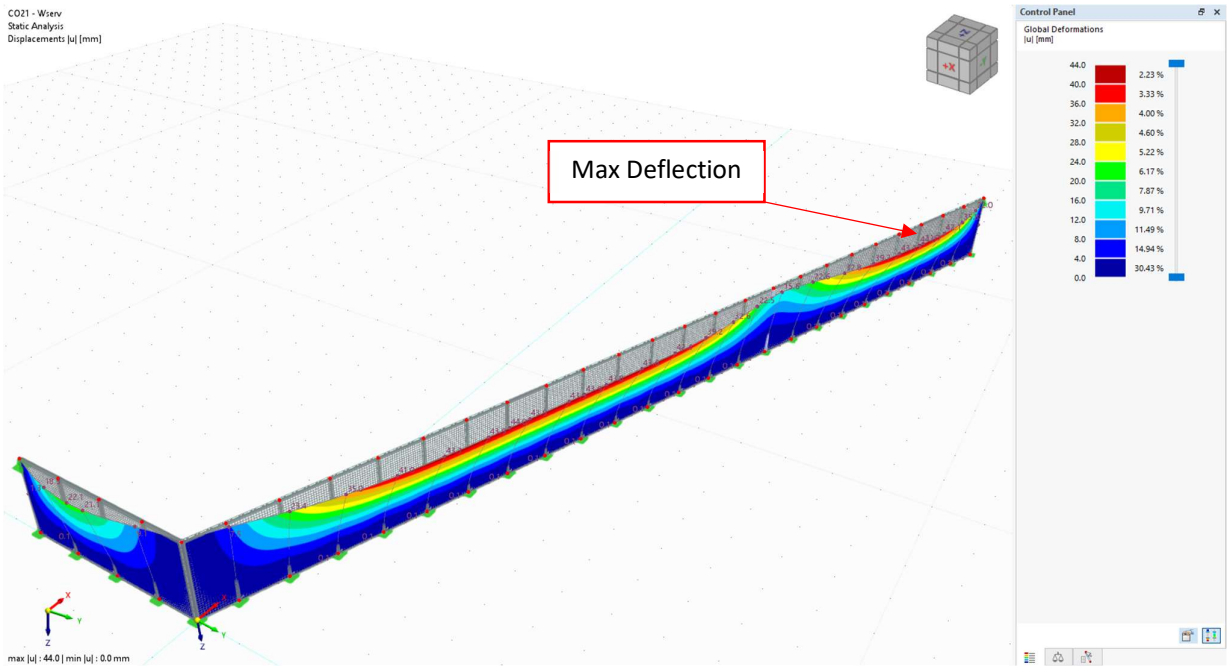


Figure 6. Global Deflection

The Glass was simulated together with the aluminum framing to account the global deflection that may occur on glass using structural analysis software, taking into account all the specified loading as discussed. Within this analysis, we scrutinized deflection and moment distributions along the glass surface. adhering to the provisions outlined in AS1288:2021 Section 7.4 (Selection of Barrier Glass), our application necessitates the utilization of Grade A safety glass for glazing purposes within the barrier system. Specifically, our application aligns with section 7.4.6, affording us the choice between laminated annealed safety glass, laminated heat-strengthened safety glass, or laminated toughened safety glass as suitable options for our project. This selection ensures compliance with the requisite safety and structural standards. Following an extensive examination of 12mm thick glass across various widths, it becomes evident that the glazing system meets the deflection limits prescribed in the Australian Standard, AS1288:2021, particularly within Section 3.3.3.

For short-term load duration, the capacity of the 12mm Laminated Heat-Strength Glass Panel with 0.785m width (most cirtical) is calculated to be **1.375 kNm** at the midspan and **1.10 kNm** at the edge. The maximum demand moment for short-term loading, as determined by the load combination 0.9G + 1.0Wu, is **0.747 kNm** at midspan and **0.991 kNm** at the panel's edge. Under short-term loading conditions, the glass is deemed adequate, with a maximum demand-capacity ratio of **90%**, satisfying the requirements of AS1288:2021 Section 3.3.

Based on calculations for medium-term load duration, the 12mm Laminated Heat-Strength Glass Panel with 0.785m width (most cirtical) has a capacity of **1.375 kNm** at the midspan and **1.10 kNm** at the edge. When subjected to medium-term loading conditions, the maximum demand moment at midspan is **0.768 kNm** and **0.608 kNm** at the edge, as determined by the load combination 1.2G + 1.5Q4. With a maximum demand-capacity ratio of **56%**, the glass is considered suitable for these conditions, which meets the requirements of AS1288:2021 Section 3.3.

However, it's noteworthy that AS1288:2021 Section 3.3.1.b provides a crucial stipulation in Note 1, indicating that if the deflection surpasses 75% of the plate thickness, it necessitates a geometric nonlinear analysis. Given that 75% of a 12mm glass thickness is 9mm, this triggered the need for a more comprehensive nonlinear analysis to determine the suitable glass type.

Under the governing loads of 0.90G+1.0Wult, the maximum equivalent stresses were found to be **42.143MPa** (Von Mises) and **45.107MPa** (Tresca). Comparing these values with the surface compression characteristics, we find that Laminated Heat-Strengthened Glass falls within the range of 24-52 MPa, as stipulated in AS1288:2021 Section 2.1.2.

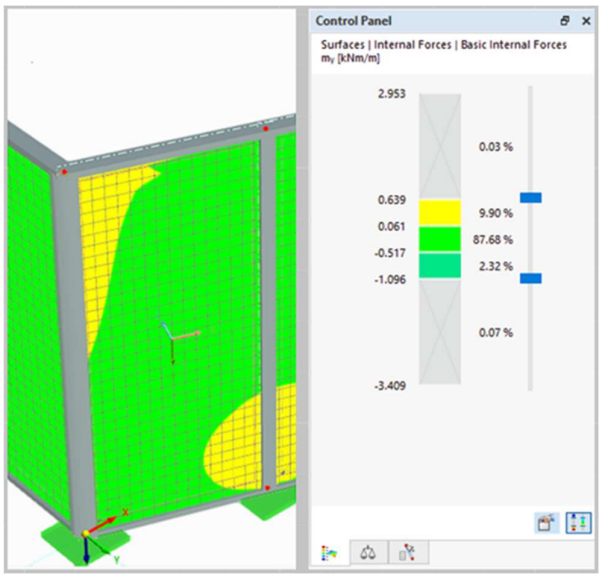


Figure 7. Short-Term Moment AlongY (My)

Maximum Governing Moment:

M (Edge) = 0.639 + 0.108 = 0.747 kNm

M (Mid span) -1.096 + 0.108 = 0.991 kNm

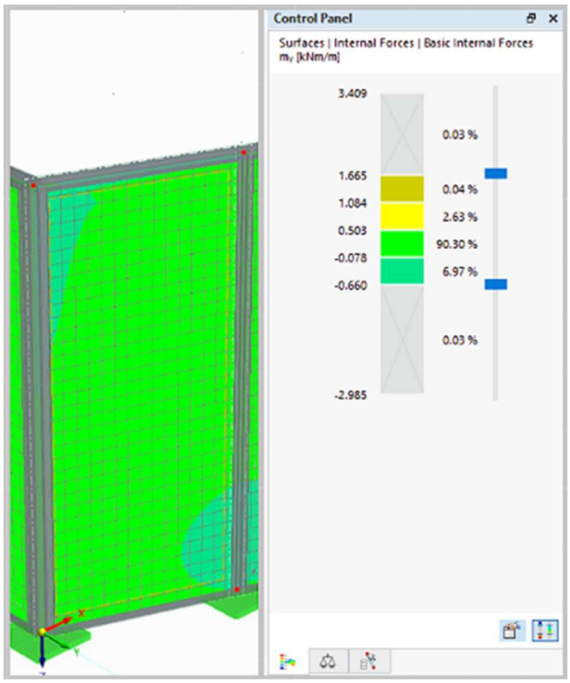


Figure 8.Medium-term Moment Along Y (Mxy)

Maximum Governing Moment:

M (Edge) = 0.66 + 0.108 =0.768 kNm

M (Mid span) = 0.503 + 0.105 = 0.608 kNm

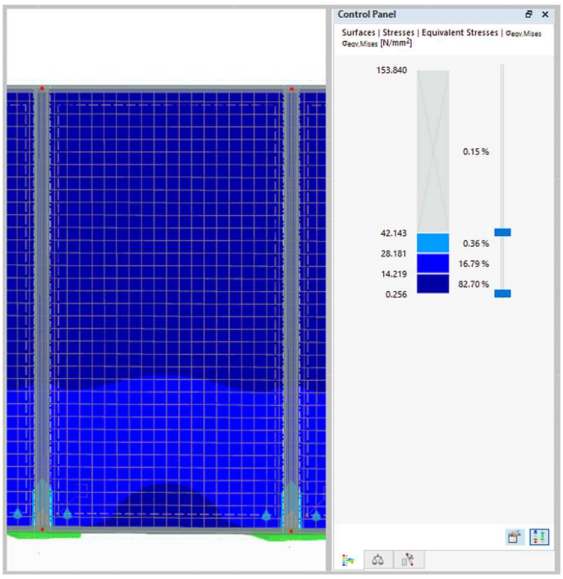


Figure 9. Von Mises Stress

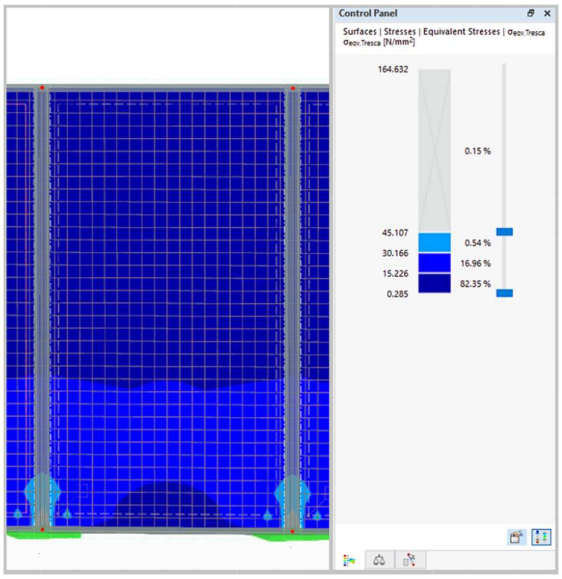


Figure 10. Tresca Stress

SCOPE #2: ALUMINUM-GLASS BALUSTRADE 04

After conducting a series of calculations and evaluations to analyze the impacts of seismic, wind, and barrier loads on the aluminum balustrade, it was established that wind loading constitutes the most critical condition. The seismic load was quantified at 0.1 kN, and the wind load, dependent on the prevailing direction, varied between 0.044 to 0.055 kN/m. Nevertheless, the wind load, which amounted to 2.50 kPa, was the most significant factor.

Following an initial examination, it was apparent that the initial segments possess the necessary strength to endure seismic, barrier, and wind loads exerted on the balustrade. The maximum design capacity ratio (DCR) for the aluminum configuration stands at 0.164. The maximum DCR for each section use in Balustrade 04 is illustrated in Figure 11. As per the deflection criteria outlined in Table C1 of AS1170.0 for Handrail-post and rail systems, the deflection limit is determined as H/60 + Span/240, resulting in 47mm. Conversely, the global deflection is computed to be 2.8mm, indicating a safe value.

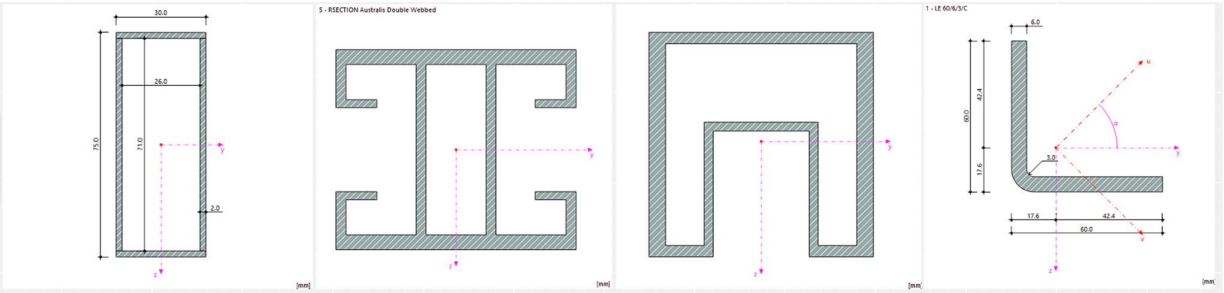


Figure 11. D/C Ratio by Section

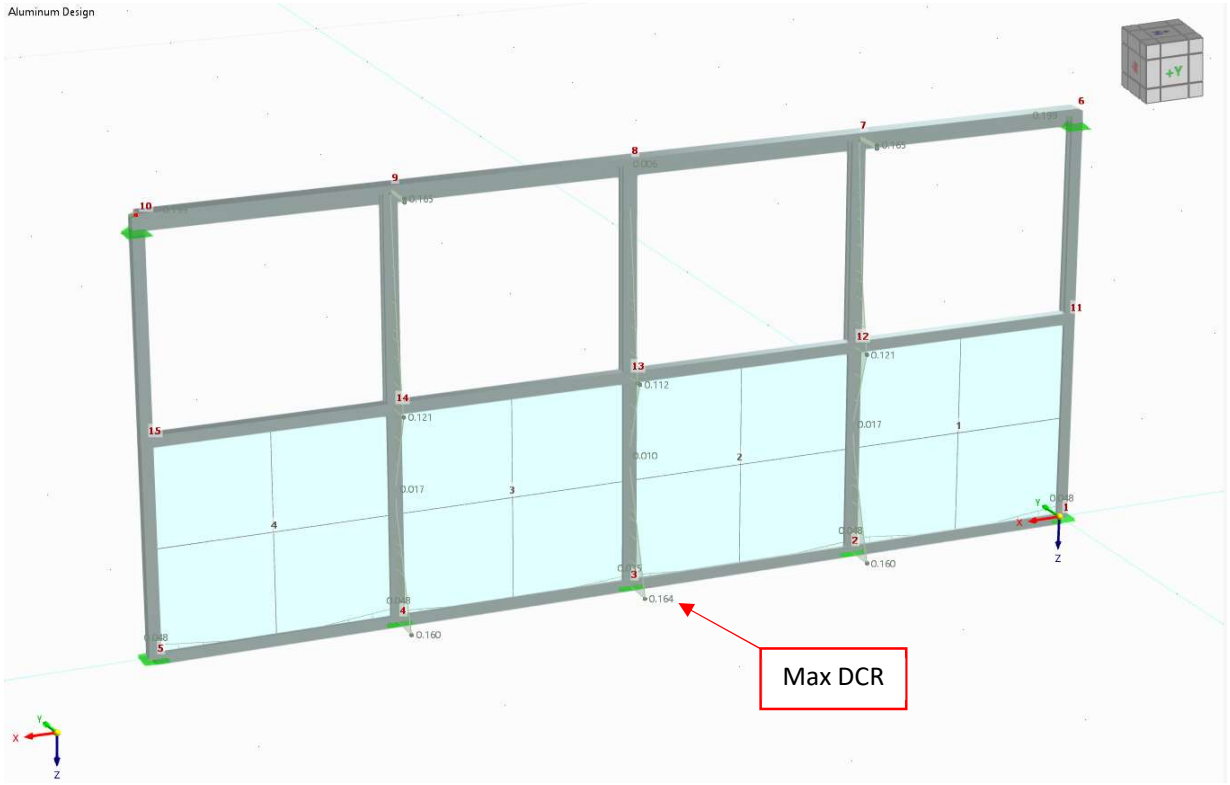


Figure 12. D/C Ratio

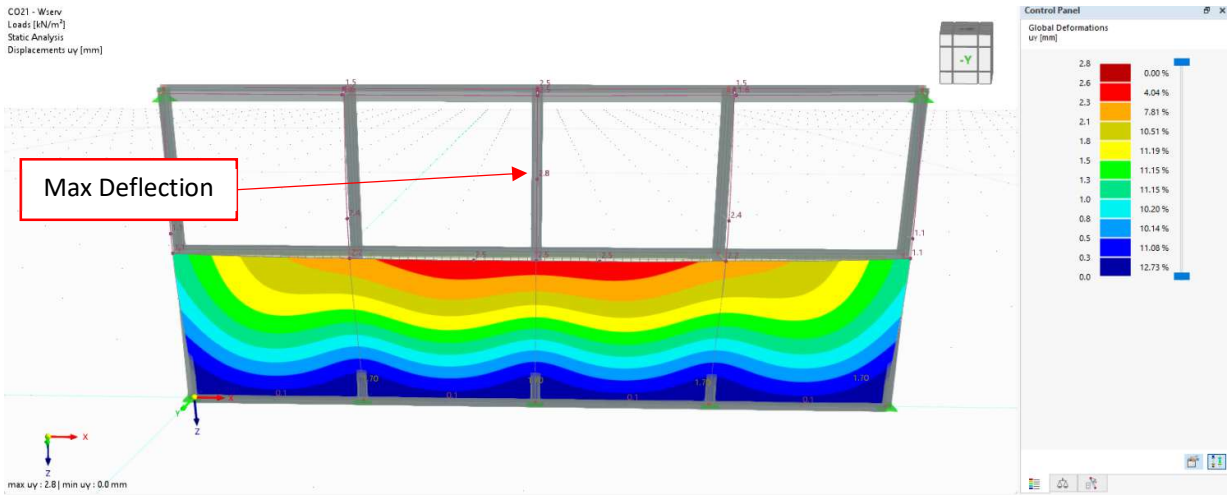


Figure 13. Global Deflection

The Glass was simulated together with the aluminum framing to account for the global deflection that may occur on glass using structural analysis software, taking into account all the specified loading as discussed. Within this analysis, we scrutinized deflection and moment distributions along the glass surface. adhering to the provisions outlined in AS1288:2021 Section 7.4 (Selection of Barrier Glass), our application necessitates the utilization of Grade A safety glass for glazing purposes within the barrier system. Specifically, our application aligns with section 7.4.6, affording us the choice between laminated annealed safety glass, laminated heat-strengthened safety glass, or laminated toughened safety glass as suitable options for our project. This selection ensures compliance with the requisite safety and structural standards. Following an extensive examination of 12mm thick glass across various widths, it becomes evident that the

glazing system meets the deflection limits prescribed in the Australian Standard, AS1288:2021, particularly within Section 3.3.3.

For short-term load duration, the capacity of the 12mm Laminated Heat-Strength Glass Panel with 0.785m width (most cirtical) is calculated to be **1.839 kNm** at the midspan and **1.471 kNm** at the edge. The maximum demand moment for short-term loading, as determined by the load combination 0.9G + 1.0Wu, is **0.128 kNm** at midspan and **0.668 kNm** at the panel's edge. Under short-term loading conditions, the glass is deemed adequate, with a maximum demand-capacity ratio of **45%**, satisfying the requirements of AS1288:2021 Section 3.3.

Based on calculations for medium-term load duration, the 12mm Laminated Heat-Strength Glass Panel with 0.785m width (most cirtical) has a capacity of **1.839 kNm** at the midspan and **1.471 kNm** at the edge. When subjected to medium-term loading conditions, the maximum demand moment at midspan is **0.077 kNm** and **0.397 kNm** at the edge, as determined by the load combination 1.2G + 1.5Q4. With a maximum demand-capacity ratio of **27%**, the glass is considered suitable for these conditions, which meets the requirements of AS1288:2021 Section 3.3.

However, it's noteworthy that AS1288:2021 Section 3.3.1.b provides a crucial stipulation in Note 1, indicating that if the deflection surpasses 75% of the plate thickness, it necessitates a geometric nonlinear analysis. With 75% of the 12mm glass thickness measuring at 9mm and the global deflection registering at only 2.5mm, it is evident that no further analysis is required.

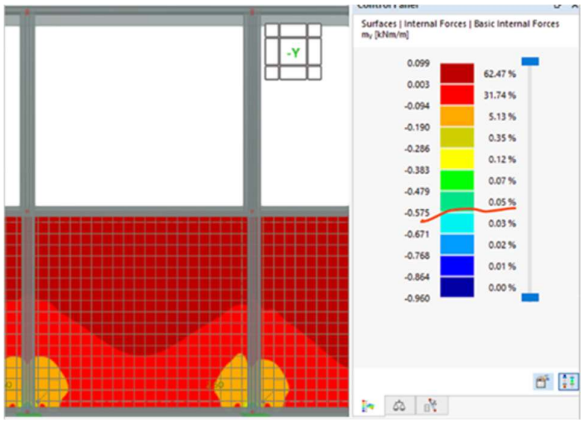


Figure 14. Short-Term Moment Along Y (My)

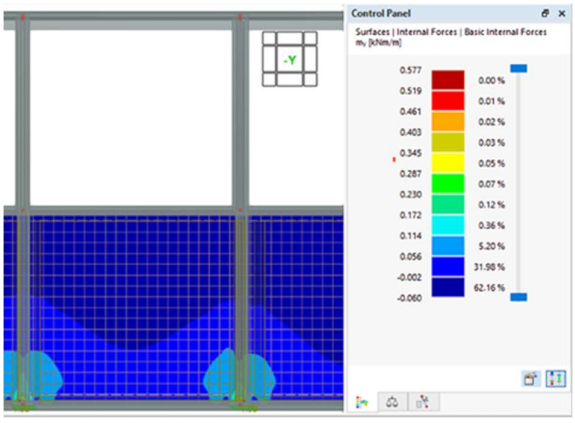


Figure 15.Medium-term Moment Along Y(My)

Maximum Governing Short-Term Moment:

M (Edge) = 0.575 + 0.086 = 0.661 kNm

M (Mid span) = 0.099 + 0.029= 0.128 kNm

Maximum Governing Meduim-Term Moment:

M (Edge) = 0.345 + 0.052 = 0.397 kNm

M (Mid span) = 0.06+ 0.017 = 0.077 kNm

SCOPE #3: ALUMINUM-GLASS BALUSTRADE 05

After conducting a series of calculations and evaluations to analyze the impacts of seismic, wind, and barrier loads on the aluminum balustrade, it was established that barrier loading (Q4) constitutes the most critical condition. The seismic load was quantified at 0.1 kN, and the wind load, dependent on the prevailing direction, varied between 0.044 to 0.055 kN/m. Nevertheless, the barrier load (Q4), which amounted to 1.0 kPa, was the most significant factor.

Following an initial examination, it was apparent that the initial segments possess the necessary strength to endure seismic, barrier, and wind loads exerted on the balustrade. The maximum design capacity ratio (DCR) for the aluminum configuration stands at 0.465. The maximum DCR for each section used in Balustrade 05 are illustrated in Figure 0. As per the deflection criteria outlined in Table C1 of AS1170.0 for Handrail-post and rail systems, the deflection limit is determined as H/60 + Span/240, resulting in 43.104mm. Conversely, the global deflection is computed to be 2.8mm, indicating a safe value.

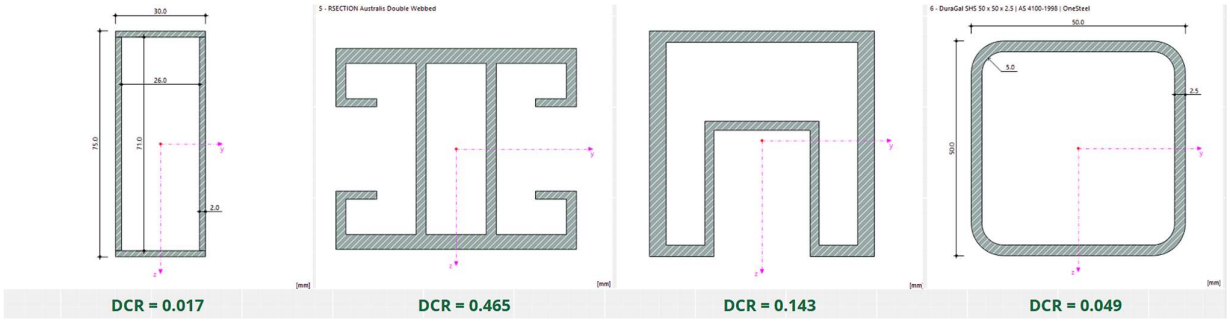


Figure 16. DCR by Section

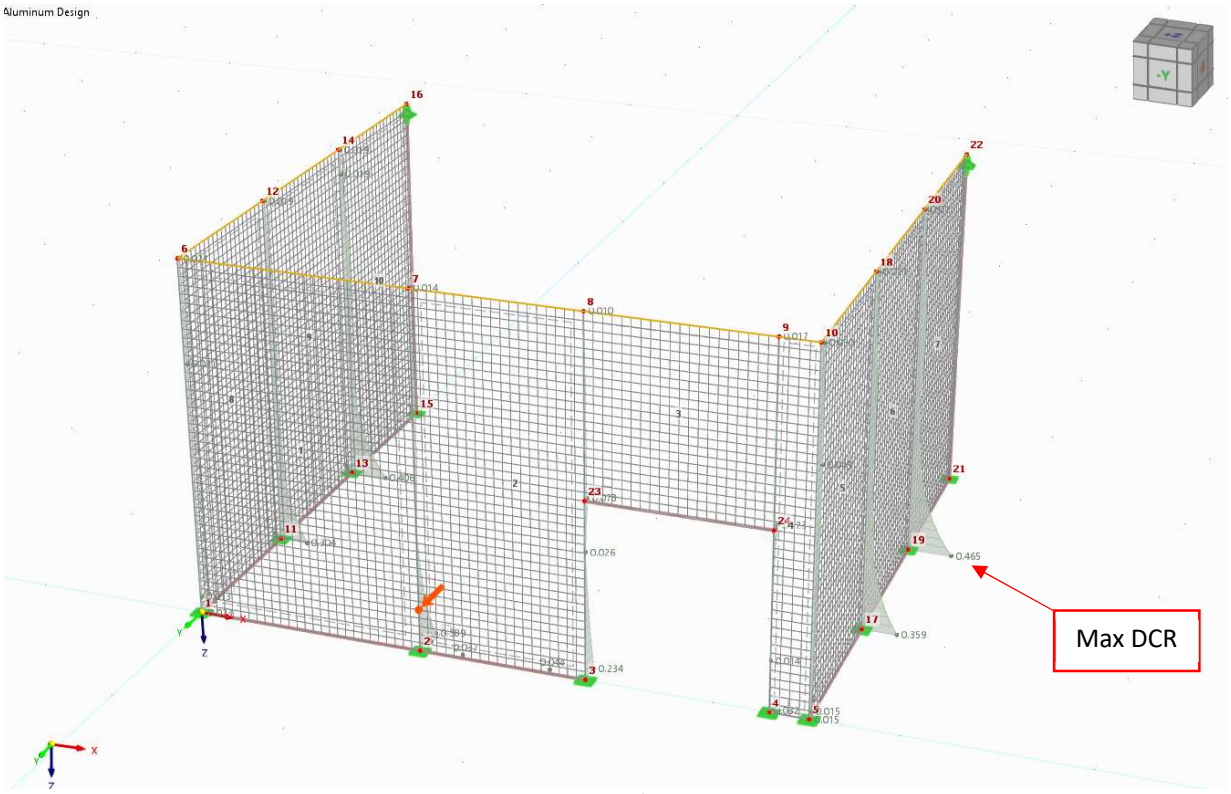


Figure 17. D/C Ratio

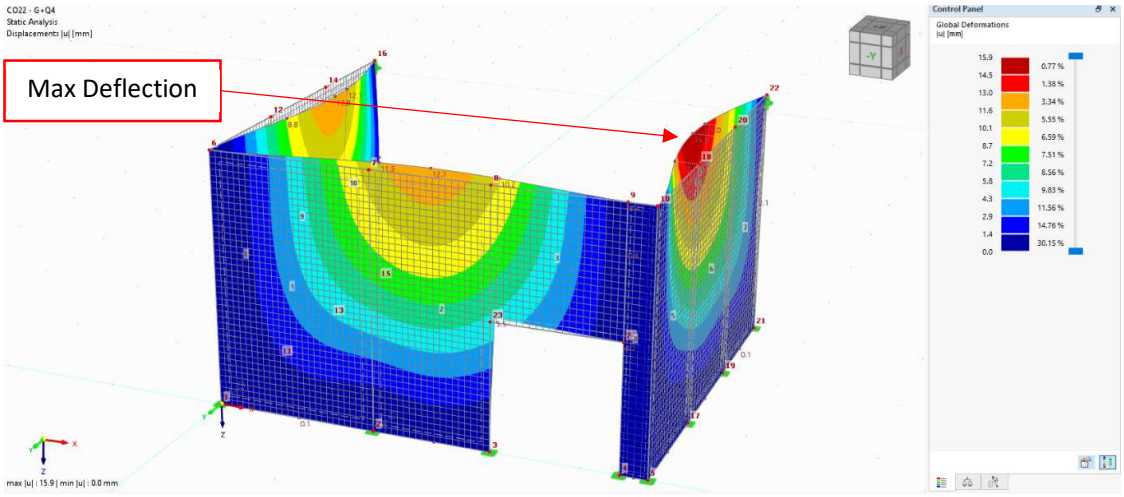


Figure 18. Global Deflection

The Glass was simulated together with the aluminum framing to account the global deflection that may occur on glass using structural analysis software, taking into account all the specified loading as discussed. Within this analysis, we scrutinized deflection and moment distributions along the glass surface. adhering to the provisions outlined in AS1288:2021 Section 7.4 (Selection of Barrier Glass), our application necessitates the utilization of Grade A safety glass for glazing purposes within the barrier system. Specifically, our application aligns with section 7.4.6, affording us the choice between laminated annealed safety glass, laminated heat-strengthened safety glass, or laminated toughened safety glass as suitable options for our project. This selection ensures compliance with the requisite safety and structural standards. Following an extensive examination of 12mm thick glass across various widths, it becomes evident that the glazing system meets the deflection limits prescribed in the Australian Standard, AS1288:2021, particularly within Section 3.3.3.

For short-term load duration, the capacity of the 12mm Laminated Heat-Strength Glass Panel with 0.785m width (most cirtical) is calculated to be **1.839 kNm** at the midspan and **1.471 kNm** at the edge. The maximum demand moment for short-term loading, as determined by the load combination 0.9G + 1.0Wu, is **0.154 kNm** at midspan and **0.494 kNm** at the panel's edge. Under short-term loading conditions, the glass is deemed adequate, with a maximum demand-capacity ratio of **34%**, satisfying the requirements of AS1288:2021 Section 3.3.

Based on calculations for medium-term load duration, the 12mm Laminated Heat-Strength Glass Panel with 0.785m width (most cirtical) has a capacity of **1.839 kNm** at the midspan and **1.471 kNm** at the edge. When subjected to medium-term loading conditions, the maximum demand moment at midspan is **0.201 kNm** and **0.853 kNm** at the edge, as determined by the load combination 1.2G + 1.5Q4. With a maximum demand-capacity ratio of **58%**, the glass is considered suitable for these conditions, which meets the requirements of AS1288:2021 Section 3.3.

However, it's noteworthy that AS1288:2021 Section 3.3.1.b provides a crucial stipulation in Note 1, indicating that if the deflection surpasses 75% of the plate thickness, it necessitates a geometric nonlinear analysis. With 75% of the 12mm glass thickness measuring at 9mm and the global deflection registering at only 2.5mm, it is evident that no further analysis is required.

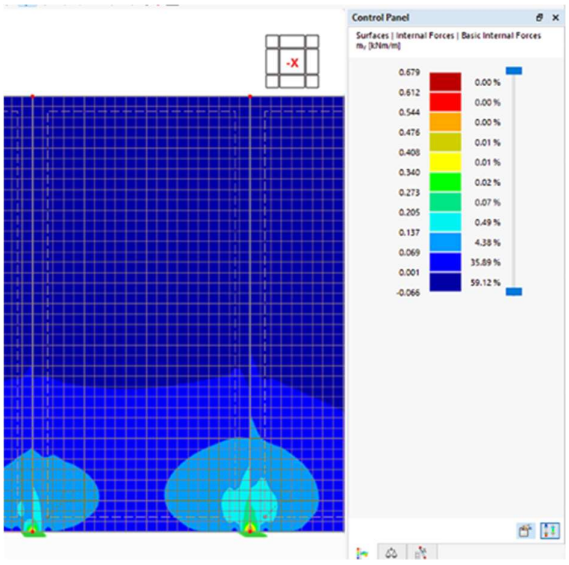


Figure 19. Short-Term Moment Along X (Mx)

Maximum Governing Moment:

M (Edge) = 0.408 + 0.086 = 0.853 kNm

M (Mid span) = 0.049 + 0.105 = 0.201 kNm

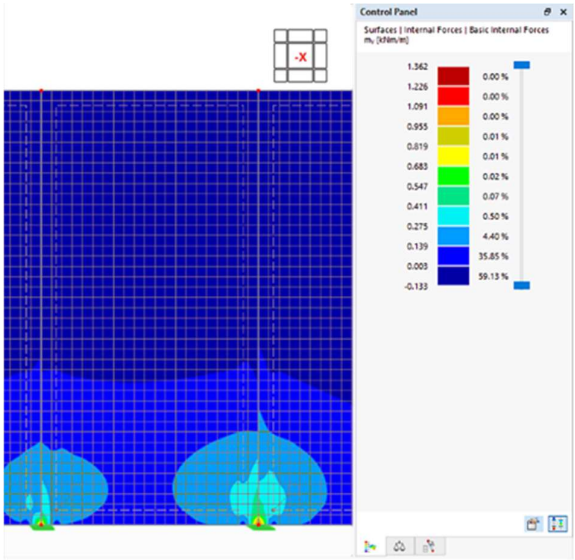


Figure 20.Medium-term Moment Along Y (My)

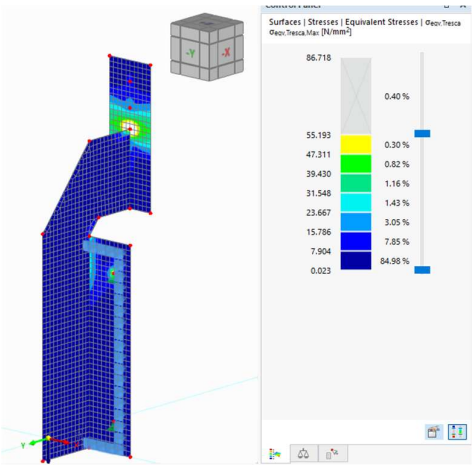
Maximum Governing Moment:

M (Edge) = 0.683 + 0.173 = 0.853 kNm

M (Mid span) = 0.099 + 0.102 = 0.201 kNm

Aluminum Bracket (for Balustrade 02)

The aluminum Bracket connections is efficiently transfer all balustrade reactions into linear and finite-element analytical models. Since the column of the balustrade is core drill the internal forces is divided to core drill and bracket. In this approach we can get conservative results. Utilizing Aluminum Grade 6060-T5, our observations indicate a maximum DCR of 0.5 and a maximum surface stress of 55 MPa. These findings confirm that the suggested fixing connection adheres to Australian standards, thereby guaranteeing structural integrity and safety.



Recommendations

1. It is recommended to ensure the connection of each member is secure properly to ensure the stability of the aluminum balustrade.
2. It is recommended to utilise Grade A Safety Glass for the balustrade to comply with the Australian Standard AS 1288:2021.

Conclusion

In conclusion, this assessment offers insight into the diverse loadings and their implications for the aluminum balustrade. Despite the challenges posed by barrier loading, the initial balustrade section proved ineffective, leading to selection of a more suitable section that aligns with the intended purpose. As a best practice, it's recommended to continue regular inspections and maintenance to ensure sustained performance and safety.

We appreciate your patronage and welcome the opportunity to discuss any further inquiries you may have.

Kind regards,

PUBLIC PORTFOLIO SAMPLE ? CLIENT, SITE AND PROJECT IDENTIFIERS REDACTED