Behavior of MSE Wall with Strips and Geogrids Reinforcement Subjected To Compaction Loadings

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Abstract: This paper focuses on the comparison of the behavior of a panel type MSE wall using the existing geosynthetic strip and steel strip reinforcement with the behavior of a suggested design of panel type MSE wall using wider geogrid reinforcement subjected to various compaction loadings and built above bedrock and stiff clay soil foundation. The behavior of the MSE wall is analyzed using finite element method in Plaxis 3D program. The numerical simulations showed that wider geogrid reinforcement exhibited similar lateral displacement with negligible difference compared to steel strip reinforcement having 26 times larger stiffness value. Also, wider geogrid reinforcement obtained higher stability level compared to strip reinforcements. The results may infer that wider reinforcement is better than narrow strip reinforcement despite the high value of stiffness in restraining deformations of MSE wall. This study also showed that the deformations of MSE wall increases and stability level decreases as the application of compaction loading increases and more when the foundation soil softens. Here, the behavior of wider geogrid with respect to strip reinforcements remained consistent upon the application of compaction loadings and change of soil foundation. Moreover, this study infer that compaction should be considered in modelling MSE wall to prevent underestimation of MSE wall deformations, which is important in design and construction.

Keywords – MSE wall, compaction effect, geogrids, steel strips, geo-strips, lateral displacement

I. Introduction

The MSE wall is composed majorly of backfill soil, reinforcement and facing system that form a composite system that is capable of sustaining lateral forces. The reinforcements improved the mechanical properties of the reinforced soil mass by compensating the tension and shear strength needed to support the soil mass against deformations. This improvement is caused by the interaction at the interface between the reinforcement and the soil wherein stresses are transferred by friction or passive resistance (Berg, et.al. 2009 [1]).

Generally, panel type MSE wall uses metal or geosynthetic strips as reinforcement material. On the other hand, block type MSE wall uses sheet type of geogrid as reinforcement material. The principle of reinforced soil is to increase the shear strength due to the restraining effect caused by the frictional force developed at the interface between the soil and the reinforcement. Therefore, the reinforcing effect can be expected to be larger as the soil-reinforcement interface is wider (Abdelouhab, et.al. 2011 [2]).

In this study, a panel type MSE wall that could use wider geogrid reinforcement than strip reinforcement is suggested. The suggested panel is designed in such a way that geogrid reinforcement can be installed between panel and panel. Henceforth, this study is going to compare the behavior of panel type MSE wall using the existing geosynthetic strip and steel strip reinforcement with the behavior of panel type MSE wall using wider geogrid reinforcement which is suggested in this study. The behavior of the MSE wall is analyzed using finite element method in Plaxis 3D program.

To study the influence of compaction on the behavior of the MSE wall, the mentioned panel type MSE walls will be subjected to various compaction loadings on every phases of the wall construction. According to Castellanos [3], the compaction equipment used within 1m from the wall facing should be a vibratory roller or plate weighing less than 4.45 kN and from beyond the 1m from the wall facing panels a roller up to 78.45 kN may be used subject to satisfactory performance (see Fig.1).

Figure 1 Compaction equipment (Castellano, 2012 [3])

II. Design of the Suggested Panel Type Muse Wall

Fig.2 shows the modified panel type facing with steel pipe slip-on, steel bar, and geogrid reinforcement connections. The steel bars and geogrid reinforcements are arranged in discrete and staggered manner having
the width of 1.20 meters and spaced horizontally at 1.50 meters on centers. The vertical spacing of the
reinforcements may vary depending on the magnitude of loads that will be supported. For the connection, the
geogrid reinforcement is wrapped around the steel bar with an adequate overlapping length. The alternating
design of the reinforcement arrangements creates an interlocking effect which could help connect the panel to
another panel and hold the two panels together during excessive deformations to prevent detachment of wall
facing element from the reinforcements. Also, this design is favorable during rare situations wherein panel
facings cannot be aligned. The connection between panel and panel plus the geogrid reinforcements help hold
the panels in place.

Figure 2 Modified panel type facing with steel pipe slip-on, steel bar, and geogrid connections

III. Three-dimensional modeling
A three-dimensional (3D) model of the MSE wall is created and analyzed using Plaxis 3D program as
shown in Fig.3. The height of the MSE wall is 6.0m above the soil foundations. There will be twelve layers of
reinforcements with elevations 0.25m, 0.75m, 1.25m, 1.75m, 2.25m, 2.75m, 3.25m, 3.75m, 4.25m, 4.75m,
5.25m, and 5.625m from the base of the wall. The reinforcement length is 4.50m (0.75H) in all layers. The
vertical spacing between reinforcements is 0.50m on-centers while the horizontal spacing varies depending on
the type of reinforcement being modeled.

Figure 3 Numerical model of MSE wall using Plaxis 3D program

There will be a 5kN compaction loading applied within 1.0m from the wall facing and 10-100kN
compaction loadings applied uniformly beyond 1.0m from the wall facing in every construction lift (see TABLE
1). The compaction load is assumed to be great to see the extent of deformations that may occur at the MSE
wall. The compaction loading is removed immediately upon the construction of the next lift. The influence of
the pore water pressure is not considered in the analyses. Nevertheless, all models have the same soil backfill,
soil foundation and wall facing material properties to avoid complexity with the results. The models are
analyzed in thirteen construction phases wherein the deformation from previous lifts are carried until the final
stage of construction. To properly compare the behavior between the panel type MSE wall using the existing
geosynthetic strip and steel strip reinforcement with the behavior of panel type MSE wall using wider geogrid
reinforcement which is suggested in this study, wall failure should not occur.

IV. Schedule of numerical analyses in Plaxis 3D
To study the influence of reinforcement width, there will be three cases of MSE walls having different
reinforcement arrangements will be analyzed in Plaxis 3D program. Case 1 refers to panel type MSE wall using
wider geogrid reinforcement which is suggested in this study. Case 2 refers to panel type MSE wall using the
existing geosynthetic strip reinforcement. And Case 3 refers panel type MSE wall using the existing steel strip
reinforcement (see TABLE 1).

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Panel type MSE wall using geogrid reinforcement</td>
</tr>
<tr>
<td>B</td>
<td>Panel type MSE wall using steel strip reinforcement</td>
</tr>
<tr>
<td>C</td>
<td>Panel type MSE wall using geosynthetic strip reinforcement</td>
</tr>
</tbody>
</table>

Table 1. Designated cases used in numerical analyses

To study the influence of compaction on the behavior of the MSE wall, four different calculations have
been performed for each cases of MSE walls. The model will be subjected to various compaction loadings in
every phases of the wall construction. During the application of compaction, a 5kPa load is applied only within
1.0m from wall facing, the rest of the areas will be subjected to the following cases. First, Case A0 refers to
MSE wall above bedrock foundation without compaction loading. Next, Case B10 refers to MSE wall above
bedrock foundation subjected to 10kPa compaction loading. Third, Case C100 refers to MSE wall above bedrock
foundation subjected to 100kPa compaction loading. Lastly, Case D10 refers to MSE wall above stiff clay
foundation subjected to 10kPa compaction loading.

V. Material parameters

5.1 Reinforcement material
The 1.50mWX1.50mH panel type MSE wall using geogrid, geosynthetic strip, and steel strip
reinforcement will be modelled according to the specified arrangements as shown in Fig.4.

Case 1 refers to panel type MSE wall using 1.20m-width geogrid reinforcement and are arranged in
discrete and staggered manner with horizontal spacing of 1.50m on centers. Case 2 refers to panel type MSE
wall using 0.10m-width geo-strips and are arranged in discrete and linear manner spaced at 0.75m horizontally
on centers. Case 3 refers to panel type MSE wall using 0.05m-width steel strips and are arranged also discretely
and aligned uniformly with horizontal spacing of 0.75m on centers.

Figure 4 Three cases of panel type MSE wall and its reinforcement arrangement
Geogrids, geo-strips and steel strips reinforcements are modeled as geogrid element with elastic
material property in Plaxis 3D. Reinforcements were assumed fixed to the precast concrete panel type wall
facing, thus reinforcement anchorage is considered. Case 1, geogrids, are assumed to be made by polypropylene
with normal stiffness equal to 1,632kN/m, elastic modulus of 940MPa and thickness of 1.45mm. Case 2, geo-
strips, are specified with normal stiffness of 750kN/m, elastic modulus of 2.5GPa and thickness of 3.0mm.
Lastly, Case 3, steel strips, have normal stiffness of 42,000kN/m, elastic modulus of 210GPa and thickness of
4.0mm (see TABLE 2).
Table 2. Reinforcement material properties

5.2 Wall facing material
A square precast concrete panel-type wall facing is designed with 1.50m width, 1.50m height, and
14mm thickness. The wall facing is modeled as plate element in Plaxis 3D. The plate is specified as linear
elastic and can resist forces in tension and compression. Properties of the wall facing are specified with unit
weight of 24kN/m³, Young’s modulus, E, equivalent to 30x106kPa and Poisson’s ratio value is 0.15 (see TABLE 3).

5.3 Backfill and foundation soil material
Soil material models characterize the stress-strain constitutive behavior of the soil. In this
study, reinforced backfill and retained backfill soils are assumed to have the same material properties to simplify
the analysis. The backfill material is categorized as Mohr-Coulomb with drained drainage type condition during
the staged construction. The backfill soil is a granular soil whose properties are as follows: effective elastic
modulus, E’, is 20,000kPa; effective cohesion, c’, is 10kPa; effective angle of friction, φ’, is 30°; Poisson’s ratio
equals to 0.40 and unit weight, γ, is 19kN/m³ (see TABLE 3).

VI. Results and Discussion

6.1 Effect of Compaction Loading
The application of 5kN compaction loading within 1.0m from the wall facing and 10-100kN
compaction loadings beyond 1.0m from the wall facing in every construction lift has significant effects on the
behavior of the MSE wall as shown in Fig.5. In this study, the compaction load is assumed to be great to see the
extent of deformations that may occur at the MSE wall. Hence, the results showed that the lateral displacement
increased when the compaction loading increased. A 100 kN compaction loading is too large for the MSE wall,
thus, exhibited large lateral displacements. This may infer that large loadings can cause great deformations on
the MSE wall which eventually leads to failure. This effect should be considered during the design of MSE wall
to prevent underestimation of the MSE wall deformations.
Figure 5 Lateral displacement at the end of the reinforcements of MSE wall above bedrock foundation
To show the amount of increase on each case, consider Case A9 as the reference model for MSE wall built on
bedrock foundation. As tabulated in TABLE 4, Case 1 has an increase of 43-50% and 817-821% after subjected
to compaction loading of 10kPa and 100kPa, respectively. Case 2 has a remarkable increase of 88-100% and
2965-3400% after subjected to compaction loading of 10kPa and 100kPa, respectively. And Case 3 has an
increase of 42-60% and 617-700% after subjected to compaction loading of 10kPa and 100kPa, respectively.
Table 4 Maximum lateral displacements, dmax (mm) percent increased (%)

Moreover, the results showed that stability of the MSE wall at the final stage of construction decreased
as the compaction loading increased (see Fig.6). The factor of safety (FS) has decreased by 8.7%, 2.4%, and
8.8% after the application of 10kN compaction load for Case 1, Case 2, and Case 3, respectively. Also, the FS
has decreased by 29.7%, 34.3%, and 29.8% after the application of 100kN compaction load for Case 1, Case 2,
and Case 3, respectively (see TABLE 5). This may imply that application of large compaction loading greatly
reduced the stability level of MSE wall.
Table 5 Factor of safety results

Figure 6 Factor of safety results
6.2 Effect of Reinforcement Width and Arrangement

The numerical simulations from Plaxis 3D program showed that for MSE wall above bedrock foundation, there is no lateral displacement at the base of the wall as shown in the Figs. 7 and 8. Also, the results showed that for MSE wall above stiff clay foundation, there is a movement of 5-8mm at the base of the wall as shown in Fig. 9. It is visible from the figures that Case 1 and Case 3 exhibited similar lateral displacement pattern with minimal differences of 1-3mm and 15-43mm when subjected to 10kN and 100kN compaction loading, respectively. The difference in lateral displacements is almost negligible taking into consideration the fact that steel strip has 42,000kN/m stiffness while wider geogrid has 1,632kN/m stiffness, approximately 26 times smaller than steel strip. However, Case 2 has a different pattern of lateral displacements compared with the other two cases. It displaced up to 16-64mm and 352-1042mm when subjected to 10kN and 100kN compaction loading, respectively. A possible failure may have occurred during the application of 100kN, which is neglected in the analysis. The behavior of Case 2 may be affected by its low stiffness value of 750kN/m and narrow width of 0.10m. The results may infer that wider reinforcement is better than narrow strip reinforcement despite the high value of stiffness.

Figure 7 Lateral displacement at the wall facing of MSE wall above bedrock foundation
Figure 8 Lateral displacement at the end of the reinforcements of MSE wall above bedrock foundation
Figure 9 Lateral displacements of MSE wall above stiff clay foundation subjected to 10kPa compaction loading

Moreover, the safety calculation results, as tabulated in TABLE 5, showed that Case 1 obtained the highest factor of safety, and Case 2 obtained the least factor of safety at the final stage of construction. This may imply that wider reinforcements have higher stability level compared with narrower strip reinforcements.

6.3 Effect of Foundation Condition

To study the influence of soil foundation on the behavior of MSE wall subjected with 10kN compaction loading, Case B10 will be compared with Case D10. From TABLE 6 we can see that Case D10 exhibited larger deformations than Case B10. Yet, Case 1 and Case 3 still showed almost equal lateral displacements with minimal difference of 1-3mm. And Case 2 also showed larger deformations compared with the other two cases.

Table 6 Maximum lateral displacements of MSE above stiff clay foundation, dx

Moreover, the panel type MSE wall constructed above bedrock foundation, Case B10 for example, obtained higher stability compared with stiff clay foundation, Case D10 as shown in TABLE 5. This may imply that MSE wall above stronger soil foundation are more stable than weaker soil foundation especially when compaction loadings are applied.

VII. Conclusion

The study compared the behavior of panel type MSE wall using the existing geosynthetic strip and steel strip reinforcement with the behavior of panel type MSE wall using wider geogrid reinforcement which is suggested in this study. The behavior of the MSE wall is analyzed using finite element method in Plaxis 3D program. To compare the influence of compaction, the mentioned panel type MSE walls are subjected to 10kN and 100kN compaction loadings on every phases of the wall construction.

Consequently, the results of the study showed that MSE wall with geogrid reinforcements exhibited similar deformations with negligible difference compared to steel strip reinforcements. Also, MSE wall with geogrid reinforcements obtained the highest factor of safety on bedrock and stiff clay foundation when subjected to compaction loadings. The results implied that wider geogrid reinforcement is more stable than narrow steel strip reinforcements despite having about 26 times higher stiffness value. Therefore, this study inferred that panel type MSE wall with wider geogrid reinforcement is better than panel type MSE wall with existing narrow strip reinforcements.

Moreover, this study showed the extent of deformations on the MSE wall when subjected to compaction loadings. The lateral displacement of the MSE wall increased and the stability level decreased when the compaction loading increased. For MSE wall with narrow strip reinforcement and low stiffness, application of large compaction may be harmful and eventually may result to failure. Thus, the effects of compaction should be considered in analysis of MSE wall to prevent underestimation of its behavior.

Lastly, this study compared the behavior of MSE wall with different soil foundation subjected with 10kN compaction loading. And the results showed that stiff clay foundation exhibited larger lateral displacements and lesser stability level compared with bedrock foundation. This may imply that MSE wall with stronger foundation is more stable and have less deformations.
Acknowledgements

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References


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Figure 3 Numerical model of MSE wall using Plaxis 3D program

Figure 4 Three cases of panel type MSE wall and its reinforcement arrangement
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(a) Case 1
(b) Case 2
(c) Case 3
Figure 5 Lateral displacement at the end of the reinforcements of MSE wall above bedrock foundation

(a) without compaction
(b) with 10kN compaction
(c) with 100kN compaction
Figure 7 Lateral displacement at the wall facing of MSE wall above bedrock foundation

(a) without compaction
(b) with 10kN compaction
(c) with 100kN compaction
Figure 8 Lateral displacement at the end of the reinforcements of MSE wall above bedrock foundation

(a) at the wall facing
(b) at the end of reinforcement
Figure 9 Lateral displacements of MSE wall above stiff clay foundation subjected to 10kPa compaction loading

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## Table 1. Designated cases used in numerical analyses

<table>
<thead>
<tr>
<th>Foundation condition</th>
<th>Cross-section of Numerical Model</th>
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<tbody>
<tr>
<td>Bedrock</td>
<td><img src="image" alt="Cross-section of Numerical Model" /></td>
</tr>
<tr>
<td>Stiff Clay Soil</td>
<td><img src="image" alt="Cross-section of Numerical Model" /></td>
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</table>

<table>
<thead>
<tr>
<th>Designation</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
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</thead>
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<td>No compaction</td>
<td>Case 1-A&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Case 2-A&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Case 3-A&lt;sub&gt;0&lt;/sub&gt;</td>
</tr>
<tr>
<td>10 kN</td>
<td>Case 1-B&lt;sub&gt;10&lt;/sub&gt;</td>
<td>Case 2-B&lt;sub&gt;10&lt;/sub&gt;</td>
<td>Case 3-B&lt;sub&gt;10&lt;/sub&gt;</td>
</tr>
<tr>
<td>100 kN</td>
<td>Case 1-C&lt;sub&gt;100&lt;/sub&gt;</td>
<td>Case 2-C&lt;sub&gt;100&lt;/sub&gt;</td>
<td>Case 3-C&lt;sub&gt;100&lt;/sub&gt;</td>
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## Table 2. Reinforcement material properties

<table>
<thead>
<tr>
<th>Case 1 Geogrids</th>
<th>Case 2 Geo-strips</th>
<th>Case 3 Steel strips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constitutive model</td>
<td>Geogrid element</td>
<td>Geogrid element</td>
</tr>
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<td>Width, w (mm)</td>
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<td>100</td>
</tr>
<tr>
<td>Thickness, t (mm)</td>
<td>1.45</td>
<td>3.0</td>
</tr>
<tr>
<td>Length, L (m)</td>
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<td>4.50</td>
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<tr>
<td>Vertical spacing, S&lt;sub&gt;v&lt;/sub&gt; (m)</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Horizontal spacing, S&lt;sub&gt;h&lt;/sub&gt; (m)</td>
<td>1.50</td>
<td>0.75</td>
</tr>
<tr>
<td>Normal stiffness, E&lt;sub&gt;A&lt;/sub&gt; (kN/m)</td>
<td>1,632</td>
<td>750</td>
</tr>
<tr>
<td>Modulus of elasticity, E (GPa)</td>
<td>0.94</td>
<td>2.5</td>
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## Table 3. Wall facing and soil material properties

<table>
<thead>
<tr>
<th>Constitute model</th>
<th>Wall Facing</th>
<th>Soil Backfill</th>
<th>Soil Foundation</th>
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</thead>
<tbody>
<tr>
<td>Drainage type</td>
<td>Plate element</td>
<td>Mohr-Coulomb</td>
<td>Jointed rock</td>
</tr>
<tr>
<td>Young’s modulus, E (kPa)</td>
<td>30x10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>20x10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>60x10&lt;sup&gt;3&lt;/sup&gt;</td>
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<tr>
<td>Unit weight, γ (kN/m&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>24</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>Poisson’s ratio, ν</td>
<td>0.15</td>
<td>0.40</td>
<td>0.30</td>
</tr>
<tr>
<td>Cohesion, c (kPa)</td>
<td>-</td>
<td>10</td>
<td>500</td>
</tr>
<tr>
<td>Friction angle, φ</td>
<td>-</td>
<td>30°</td>
<td>-</td>
</tr>
<tr>
<td>Thickness, t (mm)</td>
<td>14</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

## Table 4 Maximum lateral displacements, dx<sub>max</sub> (mm) | percent increased (%)

<table>
<thead>
<tr>
<th>Cases</th>
<th>At wall facing</th>
<th>At the end of reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case A&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Case B&lt;sub&gt;10&lt;/sub&gt;</td>
</tr>
<tr>
<td>Case 1</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Case 2</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>Case 3</td>
<td>12</td>
<td>0</td>
</tr>
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<td>Case 1</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Case 2</td>
<td>8</td>
<td>0</td>
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<tr>
<td>Case 3</td>
<td>5</td>
<td>0</td>
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</tbody>
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Table 5 Factor of safety results

<table>
<thead>
<tr>
<th>Cases</th>
<th>Case A₀</th>
<th>Case B₁₀</th>
<th>Case C₁₀₀</th>
<th>Case D₁₀</th>
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<tbody>
<tr>
<td>Case 1</td>
<td>3.158</td>
<td>2.882</td>
<td>2.025</td>
<td>2.545</td>
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<tr>
<td>Case 2</td>
<td>2.309</td>
<td>2.253</td>
<td>1.480</td>
<td>1.546</td>
</tr>
<tr>
<td>Case 3</td>
<td>3.093</td>
<td>2.820</td>
<td>1.980</td>
<td>2.493</td>
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</table>

Table 6 Maximum lateral displacements of MSE above stiff clay foundation, dx_max (mm)

<table>
<thead>
<tr>
<th>Cases</th>
<th>At wall facing</th>
<th>At the end of reinforcement</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Case B₁₀</td>
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<td>Case 1</td>
<td>20</td>
<td>23</td>
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<tr>
<td>Case 2</td>
<td>64</td>
<td>66</td>
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<td>Case 3</td>
<td>17</td>
<td>20</td>
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