ANALYTICAL STUDY FOR PERFORMANCE IMPROVEMENT OF DEVELOPED STUDS FOR STEEL PLATE CONCRETE (SC) WALLS SUBJECTED TO COMBINED LOADS

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ABSTRACT

An analytical study is conducted to investigate the effect of the shape and spacing of developed inclined studs used as shear connector between concrete and steel plate on the behavior of steel plate concrete (SC) shear walls subjected to the combined load of axial force, bending moment, and shear force. To perform it, 9 cases of finite element analyses considering the different shape and spacing of studs were carried out. The results showed that, for SC walls created by concrete and steel plate according to Design Code, the compressive strength is higher approximately 3 times than the tensile strength. Compared results from the finite element analyses of SC walls with Design Code showed that all cases were higher than design strengths. For KEPIC SNG, the moment and shear force were not influenced by the axial force of level of 0.1 to 0.2 times axial force strength. For finite element analysis results, however, it was confirmed that the higher the axial, the moment and shear strength were decreased.

INTRODUCTION

For steel plate concrete (SC) structures, entering the 2000s, the researches on the nuclear power plant (NPP) field in South Korea have begun in earnest. In 2010, KEPIC SNG (KEA, 2010), Design Code for nuclear power SC structures, was established. Unlike reinforced concrete (RC), steel plate serves as a formwork in SC structures and thus does not necessarily need to be dismantled after the completion of construction. This property enables SC structures to directly be placed and constructed at the site. In addition, it could be possible to be set up and constructed at the site after being produced by module units in the factory. Accordingly, the construction period, when using SC structures, can be remarkably shortened.

The steel plate in SC structures resists most of the shear force, making the performance of shear walls superior to that of RC walls. The self-weight of the structure is reduced, since the thickness of walls can be reduced significantly, while having the same performance as RC. This causes the inertial force to diminish, which increases the seismic safety of the structure.

SC walls are heavily filled with concrete between two steel plates and the steel plates and concrete are connected by studs, which are used as shear connectors. It is generally assumed that steel plates and concrete, connected with studs for the designs and analyses of SC walls, are perfectly bonded for composite behavior.

For most of the research on SC walls performed in domestic and a foreign country, experiments and analyses for in-plane and shear behavior have been a main concern. In recent years, for some studies (Cho et al., 2014a,b; Ozaki et al., 2004) on the behavior of the SC walls under the bending moment and axial force as well as in-plane shear force was conducted. To develop the design criteria for in-plane and out-of-plane combined loads of SC walls, Varma et al. (2014) suggested design concept based on the theory and carried out finite element analyses (FEA) using the shell element applied composite materials and its verification for the results. However, numerical analyses of composite plates assuming the state that multi-layer plates are fully attached, have limitation not to analytically review the effect of the shape and spacing of studs on the behavior of SC walls.
In this study, nonlinear finite element analyses were undertaken to examine the effect of the shape and spacing of studs on the composite behavior of non-reinforced SC walls subjected to combined load. In addition, the requirements on combined loads of KEPIC SNG (KEA, 2010) were compared the analytical results.

**DESIGN CRITERIA OF SC SHEAR WALLS (KEPIC SNG)**

**Design Code for Compression and Tension**

Primary function of SC walls is to mainly resist the shear force. However, KEPIC SNG (KEA, 2010) has design criteria for the axial force and bending moment as well as the shear force. Compressive strength $P_u$ calculates by multiplying the strength reduction factor $\phi_c (= 0.65)$ to nominal compressive strength $P_n$ as shown in Eq. (1).

$$P_u = \phi_c P_n$$  \hspace{1cm} (1)

KEPIC SNG (KEA, 2010) suggests to consider the buckling of entire walls and surface steel plates for axial compressive strength, and nominal compressive strength $P_n$ considering the buckling of entire SC walls is expressed as Eq. (2) and Eq. (3).

If the

$$P_c \geq 0.44P_0, ~ P_n = \left[0.658\frac{P_c}{P_0}\right]P_0$$  \hspace{1cm} (2)

If the

$$P_c < 0.44P_0, ~ P_n = 0.877P_c$$  \hspace{1cm} (3)

where, $P_o$: nominal compressive strength which do not ignoring the total buckling of the wall (N) ($= 2A_c F_{cr} + 0.85A_c f_{ck}$), $P_c$: elastic buckling strength(N) \(= \frac{\pi^2 EI_{eff}}{(K_u L)^2}\), $A_p$: cross section area of one side surface steel plate (mm$^2$), $A_c$: cross section area of the concrete (mm$^2$), $F_{cr}$: buckling stress of surface steel plate, $EI_{eff}$: effective flexural rigidity for calculating buckling strength of SC walls (N·mm$^2$) \(= E_s I_p + (0.6 + 2\rho_s)E_c I_c\), $K_u$: buckling length coefficient of the wall, $L$: length of walls (mm), $I_p$: moment of inertia of only both sides surface steel (mm$^4$), $I_c$: moment of inertia which do not ignoring the tensile side concrete (mm$^4$), $\rho_s$: ratio of the total surface plate area for the total wall area, $E_s$: modulus of elasticity of steel plate, and $f_{ck}$: standard design compressive strength of the concrete (MPa).

Nominal strength considering the buckling of the surface steel plate is equal to the following Eq. (4).

$$F_{cr} = (1.5 - 0.043 \frac{K_p B}{t_p} - 90\varepsilon_s)F_{yp} < F_{yp}$$  \hspace{1cm} (4)

where, $K_p$: buckling length coefficient of surface steel supported laterally by stud, $B$: vertical spacing of stud (mm), $F_{yp}$: specified design yielding strength of surface steel (MPa), $t_p$: thickness of surface
steel (mm). $\varepsilon_n$: nominal compressive strain (= 0.002 $C_{cs}$), $C_{cs}$: coefficient considering creep and drying shrinkage, $C_{cs} = 1 + \frac{P_{sus}}{\phi_c P_n} \left[ 0.016t - 0.27\sqrt{t} + 2.9 \left( \frac{32}{f_{ck}} \right)^{0.15} \right] - 1$, $P_{sus}$: sustained load For calculating the creep effect (N), $\phi_c P_n$: design compressive strength (N), and $t$: concrete age at time that sustained load is applied. Tensile strength $P_u$ calculates by multiplying the strength reduction factor $\phi_t$ (= 0.9) to the nominal tensile strength $P_n$ as shown in Eq. (5), nominal tensile strength $P_n$ is the same as Eq. (6).

$$P_u = \phi_t P_n$$

$$P_n = 2 A_p F_{yp}$$

Design Code for Out-of-plane Bending Moment

Flexural strength $M_u$ of SC walls calculates by multiplying the strength reduction factor $\phi_b$ (= 0.9) to the nominal flexural strength $M_n$ as shown in Eq. (7).

$$M_u \leq \phi_b M_n$$

where, $M_u$: required flexural strength (N-mm), $\phi_b$: flexural strength reduction factor (= 0.9), $M_n$: nominal flexural strength (N-mm). Nominal flexural strength $M_n$ is shown in Eq. (8). Tensile zone of the concrete is ignored and the strength of the compression zone is assumed as $0.85 f_{ck}$. In addition, it is assumed that the steel plate tensile side and the compression zone is uniformly distributed to the yield strength of $F_{yp}$ and the buckling strength of the surface steel plate $F_{cr}$, respectively.

$$M_n = F_{cr} A_p (T - t_p) + (F_{yp} - F_{cr}) A_p \left[ T - 1.5t_p - 0.5t_p \left( \frac{F_{yp} - F_{cr}}{0.85 f_{ck}} \right) \right]$$

where, $T$ is the wall thickness of the calculation target area (mm).

Design Code for In-plane Shear Force

The in-plane shear strength $V_u$ for the main function of the SC wall is calculated in consideration of the strength reduction factor $\phi_s$ (= 0.75) to the nominal in-plane shear strength $V_n$. The nominal in-plane shear strength $V_n$ is the value when the surface plate yields after the concrete internal crack and it is the same as Eq. (9).

$$V_n = 2 \frac{K_n + K_f}{\sqrt{3K_n^2 + K_f^2}} F_{yp} A_p$$

$$K_n = 2G_s A_p$$
where, \( G_s \): shear modulus of steel (MPa), \( \nu_s \): poisson’s ratio of steel, \( E_c' \): elastic modulus considering the diagonal tension crack of concrete (MPa), \((=0.7E_c)\), and \( E_s \): elastic modulus of the steel plate.

**Design Code for Combined Load**

Design criteria for the combined load suggest the following: axial force, bending moment, and shear force is set to satisfy the failure criterion of the Von Mises in the surface plate, and to reflect on the design after conservatively simplifying the correlation affecting one another (Eq. (12)). Where, the subscript \( z \) is the vertical direction of the wall, \( y \) refers to the horizontal direction.

\[
\begin{align*}
&\left( \frac{C_{pz}P_{uz} + C_{my}M_{my} + \beta V_u}{\phi_{P_{uz}} + \phi_{M_{my}} + \phi V_u} \right)^2 + \left( \frac{C_{py}P_{ny} + C_{yw}M_{yw} + \beta V_u}{\phi_{P_{ny}} + \phi_{M_{yw}} + \phi V_u} \right)^2 \\
&- \left( \frac{C_{pz}P_{nz} + C_{my}M_{ny} + \beta V_u}{\phi_{P_{nz}} + \phi_{M_{ny}} + \phi V_u} \right) \left( \frac{C_{py}P_{ny} + C_{yw}M_{yw} + \beta V_u}{\phi_{P_{ny}} + \phi_{M_{yw}} + \phi V_u} \right) + \left( \frac{\alpha V_u}{\phi V_u} \right)^2 \leq 1.0
\end{align*}
\]

where, \( C_{pz} \) and \( C_{my} \) are coefficients applying vertical axial force and horizontal bending moment, respectively. \( C_{py} \) and \( C_{my} \) are coefficients applying horizontal axial force and vertical bending moment, respectively. \( \alpha \): ratio of the nominal in-plane shear strength of shear strain occurred surface plate to the total nominal in-plane shear strength \((= K_{a}/(K_{a} + K_{p}))\), and \( \beta \): ratio of the nominal in-plane shear strength of diagonal tensile strain occurred surface plate to the total nominal in-plane shear strength \((= K_{p}/(K_{a} + K_{p}))\).

**FINITE ELEMENT ANALYSIS OF A SC SHEAR WALL**

FEA were conducted to assess the influence of the stud shape and spacing on the composite behavior of SC shear walls subjected to combined load of axial force, flexural moment, and shear force. Finite element (FE) models of SC walls are established with three stud spacing distances and three stud shapes. Additional verification of the FE models is omitted in this paper, as the validity of the FE model was discussed in a previous study (Cho et al., 2014a). The professional FEA program (ABAQUS), which can analyze reasonably the nonlinear behavior of SC shear walls, was utilized.

**Shape and Element of Analysis Model**

In this study, it is judged that, within the scope of the power of numerical analyses, the shape and size of the specimen used in laboratory experiment are more feasible than the actual structure’s size. Accordingly, the size of the SC wall model was determined based on the experimental data of Ozaki et al. (2004) and Kanchi et al. (1996), as follows: 1,200mm×1,200mm×206mm, and 3mm-thick and 200mm-thick for the steel plate and concrete, respectively, as shown Fig. 1.

The concrete and the steel plate are represented using C3D20R, a second-order brick element with reduced integration. The relatively small size of the stud allows it to be modeled simply as a beam element (B31). Three stud spacings are considered: 100mm, 167mm, and 250mm. The size of the stud is determined considering the thickness of the concrete, as follows: a diameter of 8mm (stud head diameter:
14mm), and a length of 50mm (body 45mm+head 5mm). There are three stud shapes used in this study, termed DS#1 & DS#2 (inclined) and GS (general), as in the study of Cho et al. (2014a,b) (Fig. 2). The slope $\alpha$ of the inclined studs is set to 35° considering the inclination of concrete cracks incurred by the pulling of general studs, in which the inclined studs are perpendicular to the crack lines of GS (Fig. 3, ACI, CCD method). The stud is assumed to be welded and completely attached to the steel plate. Table 1 explains the shape and spacing of the studs in each analysis model.

![Analytical model of a SC wall for FE analyses.](image1)

![Localized concrete crack at the stud.](image2)

**Table 1: Types and arrangement of studs.**

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Arrangement of stud</th>
<th>Type</th>
<th>Spacing (x×y)</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS-100×100</td>
<td></td>
<td>general stud</td>
<td>100mm×100mm</td>
<td>36</td>
</tr>
<tr>
<td>GS-167×167</td>
<td></td>
<td>general stud</td>
<td>167mm×167mm</td>
<td>16</td>
</tr>
<tr>
<td>GS-250×250</td>
<td></td>
<td>general stud</td>
<td>250mm×250mm</td>
<td>9</td>
</tr>
<tr>
<td>DS1-100×100</td>
<td></td>
<td>developed stud #1</td>
<td>100mm×100mm</td>
<td>108</td>
</tr>
<tr>
<td>DS1-167×167</td>
<td></td>
<td>developed stud #1</td>
<td>167mm×167mm</td>
<td>48</td>
</tr>
<tr>
<td>DS1-250×250</td>
<td></td>
<td>developed stud #1</td>
<td>250mm×250mm</td>
<td>27</td>
</tr>
<tr>
<td>DS2-100×100</td>
<td></td>
<td>developed stud #2</td>
<td>100mm×100mm</td>
<td>72</td>
</tr>
<tr>
<td>DS2-167×167</td>
<td></td>
<td>developed stud #2</td>
<td>167mm×167mm</td>
<td>32</td>
</tr>
<tr>
<td>DS2-250×250</td>
<td></td>
<td>developed stud #2</td>
<td>250mm×250mm</td>
<td>18</td>
</tr>
</tbody>
</table>

* 500mm×500mm (area considered in the evaluation)

![Type of developed studs](image3)

(a) general stud (GS)  (b) developed stud #1 (DS1)  (c) developed stud #2 (DS2)

**Figure 3. Type of developed studs (Cho et al., 2014a,b).**

**Connection of the Members and Definition of the Contact Surface**

The direct connection of a beam element to a three-dimensional solid element induces an error in
numerical analyses due to the differences in the degrees of freedom. To solve this problem, the structural coupling method in the ABAQUS interaction module is employed to connect a stud to a steel plate. The embedded element method is applied to show the status of the stud embedded in the concrete, which is defined to enable the insert element to transform according to main body’s modification when the mother body moves.

For the analyses the contact behavior between the steel plate and the concrete, a contact method based on an energy method is used and the friction behavior is defined under the assumption of the minor attaching force between concrete and steel plate. The friction coefficient (µ) of the contact surface between the steel and the concrete is assumed to be 0.5.

Properties of the Materials

Concrete
As concrete filled between steel plates shows nonlinear quasi-brittle behavior under tensile and compressive loading, in order to express this property, a concrete-damaged-plasticity constitutive model is applied. The uniaxial compressive strength of concrete and the Poisson’s ratio used in the analyses, respectively, are assumed to be 35MPa and 0.18. The modulus of elasticity is set to 29,779MPa according to Eq. (13) considering the correlation between the elastic modulus and the strength of the concrete structure standard (KCI, 2012).

\[ E_c = 0.077m_c^{1.53} \sqrt{f_{cu}}, \text{MPa} \]  

(13)

where, \( f_{cu} \) is the average compressive strength of concrete (MPa) and \( m_c \) is the unit mass (kg/m\(^3\)). The values of Table 2 are applied as plasticity parameters of the concrete-damaged-plasticity model based on research by Prakash et al. (2011). The compressive stress-strain relationship of concrete is calculated by Eq. (14), as suggested by Carreira and Chu (1985). The tensile stress-strain relationship is determined by the experiment results of Evans and Marathe (1967), while the stress-strain-damage relationship is determined according to research on repeated loadings by Jankowiak and Łodygowski (2005).

Table 2: Parameters of the concrete plastic model.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Input value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of the ultimate biaxial compressive stress to ultimate uniaxial compressive stress</td>
<td>1.12</td>
</tr>
<tr>
<td>Ratio of the uniaxial tensile to the uniaxial compressive strength</td>
<td>0.1</td>
</tr>
<tr>
<td>Dilation angle</td>
<td>35</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.1</td>
</tr>
<tr>
<td>K*</td>
<td>0.667</td>
</tr>
<tr>
<td>Viscosity parameter</td>
<td>0</td>
</tr>
<tr>
<td>*: Ratio of second stress invariant on the tensile meridian to that on compression meridian at the initial yield for any given value of the pressure invariant</td>
<td></td>
</tr>
</tbody>
</table>

\[ \sigma_c = \frac{f_{c'} \varphi \left( \frac{\varepsilon_c}{\varepsilon_c'} \right)}{\varphi - 1 + \left( \frac{\varepsilon_c}{\varepsilon_c'} \right)^{\varphi}}, \text{MPa} \]

(14)

where, \( \sigma_c \) is the compressive stress of the concrete (MPa), \( \varepsilon_c \) is the compressive strain, \( f_{c'} \) is the compressive strength, \( \varepsilon_c' \) is the strain (\( = 0.002 \)) corresponding to the compressive strength, and \( \varphi \) is identical to that Eq. (15).
\[ \varphi = \left( \frac{f_c'}{32.4} \right) + 1.55 \]  

(15)

The stress-strain-damage relationship of the concrete is shown in Fig. 4.

**Steel plate and stud**

To represent the material characteristics of the steel plate and the stud, the elastic modulus and the Poisson’s ratio are set to 207,000MPa and 0.3, respectively, while the elasto-plastic behavior is assumed to comply with the von Mises failure criteria. The stress-strain relationship of the steel plate and the stud is shown in Fig. 5 based on the research by Prakash et al. (2011). The yield strength and the tensile strength of the steel plate were 240MPa and 400MPa, respectively, while the yield strength and tensile strength of the stud was 550MPa and 710MPa, respectively.

![Stress-strain-damage relation of the concrete](image1)

![Uniaxial stress-strain relation of steels](image2)

Figure 4. Stress-strain-damage relation of the concrete. Figure 5. Uniaxial stress-strain relation of steels.

**Boundary Condition and Analysis Method**

For nonlinear analyses of SC shear walls subjected to combined load, a fully constrained boundary condition was applied to the lower portion of the wall and the vertical displacement of the lateral (+y) direction was applied to the level of 0.1 and 0.2 of nominal axial force strength to the upper portion. In addition, z-direction displacement was applied to the level of 0.2, 0.4, 0.6, and 0.8 of nominal flexural moment strength. Finally, by loading the shear load in the x-direction, the displacement control method increasing gradually the displacement until the steel plate yields was used. For numerical analyses, a modified Newton-Rhapson method was used. The results from the yield point of the steel sheet at the edges the first to yield were examined. Fig. 6 shows a conceptual diagram illustrating the analysis procedure of the SC wall subjected to combined load.

![Analysis procedure of the SC wall](image3)

(a) Step 1: axial force, (b) Step 2: out-of-plane moment, (c) Step 3: in-plane shear force, (d) Step 4: check results with multi-directional loads

Figure 6. Procedure of FE analysis.

**Verification of Finite Element Modelling**

To verify that the finite element model used in this study can express well or not the behavior of SC shear walls subjected to combined load, the results were mutually compared after analyzing in-plane tension
and compression behaviors based on the finite element model using the shell element (Varma et al., 2014) and applied composite materials. For models used the shell element and three-dimensional models that meet Design Code, the same material properties and boundary conditions were applied on the basis of the model of the vertical stud distance of 100mm. Fig. 7 shows a comparison between Varma et al.’s Study (2011), 3-D models in this study, and Design Code and the nominal strength of KEPIC SNG (KEA, 2010). 3D model arranged studs in accordance with Design Code and the nominal strength of KEPIC SNG showed almost similar results with values from the shell model applied composite materials. From this, the 3D model of this study for combined load was confirmed to be valid. In Fig. 7, Zone A, Zone B, Zone C, and Zone D mean biaxial tensile zone, tensile and shear zone, compression and shear zone, and biaxial compression zone, correspondingly. In the case of Zone D, the reason the compression zone of the concrete above Design Code is because, for Design Code, the reduction factor of 0.65 in the nominal strength was considered. For finite element analyses, however, hardening and softening behavior of concrete is because to proceed.

Zone A is tensile zone and, in design, it does not take into account the stiffness of the concrete. In finite element analysis results, it was also confirmed that, since concrete was destroyed before the yield of steel, it was found not to affect.

From Fig. 7, when assuming the SC wall with full one body, for finite element analyses, the compressive strength compared to the tensile strength of the steel plate was found approximately three times as large, while Design Code is approximately 1.9 times greater. This is because, for Design Code in compression, the strength is very conservatively estimated in consideration of the strength reduction factor 0.65.

Figure 7. Comparison of interaction surface for composite SC wall panels in principal force space.

![Figure 7](image)

(a) axial compressive force (b) out-of-plane moment (c) in-plane shear force

Figure 8. Comparison of design strength with FEM results.

**ANALYSIS RESULTS AND EVALUATION**

**Evaluation for a Single Load**

As described earlier, design criteria for the axial force, flexural moment, and shear force are conservative than the nominal strength derived on the basis of theoretical background and, in order to have the reliability, they consider the strength reduction factor. Fig. 8 shows the change of strengths obtained from the design strength and finite element analyses when the spacing of studs for shear walls that had targets in the analyses of this study is changed to 100mm, 167mm, and 250mm.

In the case of axial force, the finite element analysis results compared to the design strength were higher 1.1 through 1.3 times. For the moment, the analysis results compared to the design strength were higher 1.4 through 2.1 times. These results are because, when the design strength of SC walls for axial force and bending moment is calculated, the consideration for the buckling of the composites member outer steel
plate was estimated a very conservative. For in-plane shear forces, design strength showed no correlation with stud spacing. For finite element analyses, however, it was confirmed that the strength is lowered as the distance of stud increases. In addition, the change compared to axial force and bending moment was not significant and Design Code is also judged to reflect this trend.

**Analysis Results for Combined Load**

With respect to the spacing and shape of studs, by the method mentioned above, axial force, bending moment, and shear force was loaded in turn to finite element model of SC shear walls. Fig. 9 shows finite element analysis results obtained in this study and KEPIC SN G (KEA, 2010) based on the relationship between shear force and out-of-plane moment. Where, to quantitatively evaluate the correlation between analysis results and Design Code, it was expressed as the strength ratio by dividing the analysis results to the design strength.

In Fig. 9 (as shown in Fig. 8), in the case of moment compared to the shear force, it can be seen that the strength of SC walls obtained by analyses is greater than Design Code. This is because, as mentioned earlier, design strength for bending moment considers the buckling of the outer plate.

![Figure 9. Relationship between shear force and moment.](image)

For the properties of the SC structure considered in the analyses of this study, the results calculated the compression force contribution factor $C_{cz}$ and $C_{cy}$ for moment and shear force based on the KEPIC SNG - were between 0.7 and 1.0. Following the Design Code for combined load, the axial force of 0.1 and 0.2 times the nominal strength did not affect the moment and shear force. For finite element analysis results, however, it was confirmed that the higher the axial, the moment and shear strength were decreased. The case of the stud spacing 100mm, satisfying Design Code for the stud spacing, showed a higher level than the conservative design standards. However, some cases of the 167mm and most cases 250mm showed overlap with Design Code. This is because, when incomplete synthesis occurs by widening of stud spacing, it does not meet the required Design Code since the excessive local buckling occurs in the surface plate. Looking at the results according to the type of stud, the inclined stud showed strength ratio slightly higher than that of the general stud. When there is no axial force, however, the effect was insignificant. When the axial force is applied, compared to there is no axial force, the increase of strength ratio was more apparent. In addition, the difference between inclined studs DS1 and DS2 was minor.

**SUMMARY AND CONCLUSIONS**

This research has analytically examined the effect of the shape and spacing of studs, the shear connector used in NPPs, on the behavior of SC walls subjected to combined load. More specifically, compared to the design criteria, the following results were obtained.

Compared to the results for in-plane tension and compression of SC shear walls created well according to Design Code for steel-plate concrete structures, compression strength is greater approximately 3 times than that of in-plane tension strength. Comparison to Design Code after performing numerical analyses
for the behavior of SC shear walls subjected to combined load, using finite element method considered the plasticity and damage of concrete, showed a result that exceeds the design strength. More specifically, for moment, the design criteria considering the buckling of the surface plate was the most conservative. According to KEPIC SNG, although axial force of 0.1 to 0.2 times the nominal axial force strength does not affect, however, analysis results showed that moment and shear force decreased with the increase of axial force. In the case applied the vertical load on the wall, the shear strength and flexural strength due to developed studs were slightly increased and the result difference with type of developed studs was not significant.

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