Effects of segregation on reinforced concrete column, a numerical approach

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Abstract. Columns are parts of building members that are exposure by the risk of segregation due to the elements’ dimension ratio, characteristic of concrete mix, and the concrete casting method. The segregation will create a higher density of coarse aggregate in lower part of the columns and result non-uniform distribution of concrete strength along the columns’ height. In previous research, the segregation on RC column were proven to decrease the performance of the member in withstanding the working load. As a result, the resulting ultimate load decreased up to 4% compared to the normal column. The segregation also decreases the level of ductility of the column, which was supported by the decrease of top drift on the segregated column. The researchers also found that segregation on RC column could change the failure mechanism from tension-controlled failure to compression-controlled failure. The failure on segregated column was initially begun by the crushing of concrete on the compression fibre and followed by the yield of tensile rebar. On the normal column, on the other hand, the failure on was initially begun by the yield of tensile rebar and followed by crushing of concrete on the compression fibre. In this paper, researchers would like to investigate the behaviour of segregated RC column using numerical approach. The results showed that (1) the segregated column creates a linear drift pattern, while the normal column shows a graph with double curvatures at the ultimate condition; (2) the resulting stress contour showed a similar pattern in the segregated column and in the normal column, while the normal column could withstand working stress up to 25% higher than the segregated model; and (3) column drift from numerical analysis is more reliable than the experimental works as the experimental data only provided the reading of drift at two level of column height.

1. Introduction

In structural analysis, building elements, such as reinforced concrete beams, columns, and plates, are assumed to have a homogeneous strength on the entire part of the elements. It ignores the reality that concrete undergoes the segregation and/or bleeding that change the material distribution on elements’ height. The use of coarser aggregate and the higher water-to-cement ratio will decrease the viscosity of concrete mix and increase the possibility of concrete to occur segregation. The segregation will create a higher density of coarse aggregate in lower part of cast element and result less concentration in the upper part. This effect will be more obvious in the depth elements such as columns. In the same time, bleeding will separate the cement-water from the concrete mix and leave the water pockets under the coarse aggregates that reduce the concrete strength.
Hidayat [1] stated that segregation is influenced by the concrete mix proportion, casting methods, and concrete compacting methods. The present of segregation causes the concrete to create a different concrete strength pattern as a function of elements’ height. It was found that the segregation created a higher concrete strength laid at the bottom while gradually decrease to the upper part. This finding was supported by the reading of hammer test procedure conducted on the deep beam in the existing building.

Corinaldesi [2] also conducted research regarding segregation phenomenon on the concrete specimens sized of 80 x 80 x 1000 mm. He utilised Ultrasonic Pulse Velocity (UPV) apparatus to inspect the wave velocity on each specimens’ height. The research resulted that the higher the reading position is, the lower velocity is recorded from the testing. The highest velocity is found the extreme lower fibre of the specimens. The velocity of UPV is highly related to material density. The higher material density increases the resulting velocity reading. The higher material density in concrete is indicated by the increase of coarse aggregate percentage at the inspected part, meaning that the higher velocity in the lower part of concrete member is caused by the high concentration of coarse aggregate. The lower velocity in upper part of concrete element is caused by the less percentage of coarse aggregate. It is concluded that deep elements are prone to segregation and change the material homogeneity that effects the performance of the designed elements.

Columns are parts of building members that function to withstand axial loads besides shear and moment that arise due to lateral loads. The columns that are insufficiently designed to lateral loads will undergo shear failure and create a brittle failure mechanism that endangers the building host [3-4]. The experimental works focusing on the behaviour of RC column undergone segregation had been conducted by Pratama [5]. The result showed that the segregation on RC column decreases the performance of the element. The segregation leads the coarse aggregate to sink at the bottom of column and creates a gradual strength pattern from the upper to the lower part of the column. As a result, the achieving ultimate load decreased up to 4% compared to the normal column. The segregation also decreases the level of ductility of the column, which is supported by the decrease of top drift on the segregated column. The researchers also found that segregation on RC column could change the failure mechanism from tension-controlled failure to compression-controlled failure which was evidenced by the reading of strain gauge installed on tensile rebars and on the concrete compression fibre. The failure on segregated column was initially begun by the crushing of concrete on the compression fibre and followed by the yield of tensile rebar. On the normal column, on the other hand, the failure on was initially begun by the yield of tensile rebar and followed by crushing of concrete on the compression fibre.

In this paper, researchers would like to investigate the behaviour of segregated RC column using numerical approach. The resulting data, particularly consisting load – top drift data and stress concentration will be compared with the experimental data on the previous research. This paper aims to complement the research findings regarding the effect of segregation on RC column.

2. Finite element modelling
The detail of the testing columns followed the specification of Pratama’s research [5]. The RC columns size of 150 x 150 x 1000 mm with reinforcement configuration 4Ø8 mm for the longitudinal bars (reinforcement ratio = 1.17%) and Ø6-100 mm for the stirrups were modelled in Strand7. The reinforcement detailing of columns is displayed in Figure 1.

The idealization of column specimen underwent segregation also adapted from the research of Pratama [5]. In that research, the observation was focused on the upper section of the column that possessing lower strength and was exposed to the higher risk of shear force concentration when the lateral load occurs. The illustration of column modelling is depicted in Figure 2.

In finite element programme, the segregated column was modelled by creating multiple layers of concrete with strengths that gradually change with the function of column height. In this case, the researchers applied a linear pattern to relate the strength on the extreme top fibre to the extreme bottom fibre of the column. This modelling approach is so-called with ‘layerwise homogenisation’ method [6-13]. The layerwise homogenization method is the best solution to reduce the degree of freedom on the model constructed from heterogeneous materials and will decrease the running time during the analysis.
During the modelling, material parameters consisting of, at least, Poisson ratio, density, stress-strain table, and failure criteria are input to the programme. The failure criteria used in this research was Max-Stress so the failure of nodes is evaluated by the maximum stress of materials. The materials were set as isotropic. To model the interaction of rebars to concrete, there are three alternatives, that are the discrete model, the embedded model, dan the smeared model. In this research, researchers used the
discrete model, which idealized the rebars as beam elements connected to concrete nodes. The concrete elements were modelled using plate. The illustration of discrete model and the model of segregated column is shown in Figure 3.

![Figure 3](image_url)

**Figure 3.** (a) Discrete modelling [6], (b) Column modelling in Strand 7

3. Results and discussion

3.1. Drift ratio – column height relationship

Figure 4 shows the drift ratio of the segregated column and the normal column under the lateral loads at the ultimate condition. The drift ratio was obtained by comparing drift on each level with the ultimate drift of each model. Figure 4 presents that the segregated column creates a linear drift pattern, while the normal column shows a graph with double curvatures.

![Figure 4](image_url)

**Figure 4.** Drift ratio of the segregated column and the normal column
3.2. Stress contour

The appearance of stress contour will help the researchers to investigate the stress distribution and the stress concentration on the testing models. The resulting stress contour in Figure 5 shows a similarity in the segregated column and in the normal column. The lateral loads created tensile stresses and compressive stresses area on the models. Based on the data of plate stress, the highest stress is found in the normal concrete model with a difference up to 25% than the segregated model. A small difference is found in the area of tensile stress that is lesser in the segregated column. This phenomenon will lead the segregated column to undergo compression failure rather than the tensile controlled failure. It supports the findings on the previous research [5] that the segregation alters the failure mode and also decrease the structural ductility of the column.

![Stress contour](image)

Figure 5. Stress contour on (a) segregated column, and (b) normal column

3.3. Drift comparison of the segregated column from experimental works and finite element analysis

Figure 6 shows the data of the drift pattern of the segregated column from the numerical analysis and the previous research [5]. In terms of drift pattern, the experimental data shows a nearly linear pattern which the column drifts with the same inclination from lower part to the mid-top part. Meanwhile, the numerical analysis shows a less drift at support area and begin to sway in linear pattern to the upper section.

In experimental works, three pieces of dial gauge were installed at the bottom-end, mid-height, and top part of the column. The dial gauge set at the bottom part was aimed to control the stability of testing specimens during the loading. This testing setup only provided the reading of column drift at two levels, which were at the mid-height and the top part. Therefore, the drift data from experimental works was not able to represent the actual drift pattern during the loading. In numerical simulation, the column drift is generated from the displacement of nodes along the centroid of column height. In this case, drift data of column from numerical analysis is more reliable than the experimental works. It is supported with the drift data on the lower part of column that is lesser due to the presence of restraints positioned at the bottom-end part of column.
Figure 6. Drift comparison on the segregated column from experimental works and finite element analysis

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