Impact Analysis of Reinforced Concrete Columns with Side Openings Subjected to Eccentric Axial Loads

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ABSTRACT

In this research the behavior of reinforced concrete columns with large side openings under impact loads was studied. The overall cross sectional dimensions of the column specimens used in this research were (500*1400) mm with total height of (14000) mm. The dimensions of side openings were (600*2000) mm. The column was reinforced with (20) mm diameter in longitudinal direction, while (12) mm ties were used in the transverse direction. The effect of eccentric impact loads on the horizontal and vertical displacement for this column was studied.

Nonlinear finite element analysis has been carried out using ready computer finite element package (ANSYS) to simulate the behavior of the reinforced concrete column with large side openings. Two load cases were considered in this investigation (C1, C2) with three different load values for each case. In the first case (C1) the loads was applied to one side of the column and in the second case (C2) the loads was applied to both sides. An Equilateral triangular load-time function was used for simulation the impact load results from gantry cranes supported by the column with total time duration (0.1 sec).

In order to verify the analysis method, as no experimental data exist for comparing the obtained results, another analysis is made for tested conventional column under impact load at mid-height and good agreement has been obtained.

For the above mentioned column, the maximum displacements were (33.3, 22.2) mm in the horizontal and longitudinal direction respectively, location of the maximum horizontal displacement was at the crown of the column. By comparing the results of the first loading case with the second one it is shown that in the horizontal direction, maximum displacement increases by (139%), (208%), and (147%) respectively, also the maximum vertical displacement increases by (150%), (172%), and (172%) respectively.

Key words: impact analysis, concrete columns, columns with side openings, eccentric loads.

التحليل الصدمي لأعمدة خرسانيه مسلحة حاوية على فتحات جانبيه ومعرضة لأحمال محورية لا مركزية

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الخلاصة

في هذا البحث تم دراسة سلوك عمود خرساني يحتوي على فتحات جانبية كبيرة (عمود ذو جزئين) تحت تأثير احمال صدمية لامركزية, حيث تم اعتماد عمود ذو مقطع (500*1400) ملم وبأرتفاع (14000) ملم ويحتوي على فتحات جانبية كبيرة بأبعاد (600*2000) ملم وتم تسليح العمود بأستخدام حديد بقطر 20 ملم في الاتجاة الشاقولي وقطر 12 ملم في الاتجاه العرضي .وتم دراسة تأثير تغير مقدار التحميل على الازاحه لهذا العمود.

تم اعتماد التحليل اللاخطي بأستخدام طريقة العناصر المحدده وبالاستعانه ببرنامج (ANSYS) ليُحاكي تصرف العمود المحتوي على فتحات جانبيه وتم تسليط الاحمال بحالتين وكل حالة تحتوي على ثلاث قيم مختلفة للحمل ,حيث في الحالة الاولى تم التحميل من جانب واحد وفي الحالة الثانيه تم التحميل من جانبين, , وتم استخدام دالة حمل مثلثة الشكل متساوية الساقين لتمثيل الحمل الصدمي المسلط خلال فترة تحميل تبلغ (0.1) ثانيه.

اكبر ازاحه تم الحصول عليها كانت (33.3) ملم مع المحور (X) و (22.2) ملم مع المحور (Y), وأن موقع اكبر ازاحه افقيه كان عند قمة العمود. وعند مقارنة النتائج لحالتي التحميل (التحميل من جانب واحد والتحميل من الجانبين) تبين ان نسبه الزياده في الازاحه الافقيه هي (139%, 208% , 147%)على التوالي, في حين ان نسبه الزياده في الازاحه العموديه هي (150%, 172%, 172%) على التوالي .

1. INTODUCTION

1.1 General

Openings and holes are used in reinforced concrete columns for providing access for services like plumbing, water network, electric and communication system etc. In some cases it is required to use very long column to carry light load like the columns of ware house. In this case using column with small cross sectional area leads to stability problem due to large slenderness ratio and using column with large cross sectional area may become uneconomical, therefore, the designer heads towards using two-legs column with large horizontal opening between two sides of the column, which provides both stability and economy.

A lot of research work were studied the behavior of longitudinal hollow column like **Cheng et al., 2005, Lignola et al., 2007,** and **Ali Al- Ahmed,2010**. Also, few researches were studied the behavior of column with side openings as Son et al. in 2006.

1.2 Objectives of Present Study

The objective of the present work is to investigate the deformation characteristics of the two-leg concrete column with large side openings subjected to eccentric impact load. The research covers the behavior of column under different load cases and different load values applied to an individual selected column.

2. FINITE ELEMENT MODELING

2.1 ANSYS Model

The ready package finite element computer program designated ANSYS version 11.0 has been used for modeling the reinforced concrete column. The dimensions of the modeled column was (14m) in height and with different cross sections along its length, **Fig.1** shows overall dimensions of the column with location of some sections, these cross sections are shown in **Fig.2**.

2.1 Element Types

Solid65 element type was used for modeling the concrete, while Solid45 element type was used for modeling steel base plates at the corbel of the column. Link8 element type was used for modeling steel reinforcement in all directions.

2.2 Real Constants

In the finite element simulation, the second step after choosing the elements type, is giving the value of real constants. For Soid65 all input data equal to zero and that physically means no smeared reinforcement was chosen for this simulation, where the analysis forward in the direction of discrete reinforcement approach, therefore, the cross sectional areas for link8 elements were (314 and 113mm^2) for longitudinal and transverse reinforcement respectively.

2.3 Material Properties

In this research, material nonlinearity was considered for steel and concrete. Five points stress – strain curve was selected for concrete with compressive strength of (25) MPa and Poisson's ratio of (0.17).

Bilinear stress – strain hardening curve was used for steel reinforcement with yielding stress of (420) MPa and Poisson's ratio of (0.3).

2.4 Modeling

The concrete column were modeled using ten distinguish volumes; these volumes are shown in **Fig.3**.

2.5 Meshing

In order to obtain accurate simulation of this column with exact location of openings, concrete covers and location of steel bars in both longitudinal and transverse direction, small element length of (40) mm was chosen for this analysis and that leads to huge numbers of nodes and elements. In the other hand, these numbers allow the model to capture the real behavior of the column. Total (116928) nodes and (108441) different elements were exist along the column.

2.6 Supports

The supports were modeled in such a way that fix reaction was created by restraining the translation in X, Y, and Z directions at the base of column.

2.7 Loading

Two main impact load cases was considered in this research, in the first load case, the impact load was applied to one side of the column (in both vertical and horizontal directions) and it's called (C1), and in the second load case the load was applied to both sides of column at the same time (in both vertical and horizontal direction) and it's called (C2). Load cases are shown in **Fig.4** and **Fig. 5.** Furthermore each case has three stages of impact loading, where the first loading stage is (30 kN and 15 kN) for vertical and horizontal directions respectively, second loading stage is (50 kN and 25 kN) for vertical and horizontal directions respectively, and third loading stage is (100 kN 50 kN) for vertical and horizontal forces respectively. The impact load was simulated as equilateral triangular function with load time duration of (0.1) sec and maximum load occur at (0.05) sec. **Fig.6** shows variation of load with time and the value of loading was chosen theoretically on the bases usual range of gantry-crane load carrying capacity for factories and warehouses.

3.VERIFICATION EXAMPLE

To prove that the proposed method for modeling reinforced concrete columns with side openings under the influence of impact loads match of the correct method, and because of the absence of the required information from experimental test results or other theoretical analysis procedure. For this reason an ordinary reinforced concrete column has been modeled using finite element method under the same types of loads (impact loads) and the numerical values of displacement obtained from analysis was compared with experimental test carried by Remennikov and Kaewuaruen (2006). **Fig.7** presents load-deflection curve for the reinforced concrete column under transverse impact load. Investigation of this curve shows acceptable agreement between experimental test results and the proposed finite element model.

4. NUMERICAL RESULTS

The behavior of the analyzed column under impact load will be studied by investigating the displacements at different nodes along the column. Locations of these nodes are shown in **Fig.8**.

4.1 Displacement Along the Column

The horizontal displacement due to maximum loading at time (0.05) sec is shown in **Fig. 9** and **Fig.10** for load-cases C1 and C2 respectively. The horizontal displacement means the displacement along the x- axis and is called (Ux). From these figures it’s obvious that column behavior goes in three parts for all cases. First part starting from the base of column (N1) to the level of (N9) where there is increase in horizontal displacement with height. The second part covers the region between (N9) to (N11) where there is small increase in lateral displacement as this solid part of column displaces approximately as one unit. The third part of the curve covers the region between (N11) which represents the points of applying load to (N13) which represents top of column, where large horizontal displacements are noticed due to rotational effect of solid part of column under the neck.

By comparing the results in **Fig.9** for node (N11) it is seen that the increase in the impact force from (15) kN to (25) kN (from C1L1 to C1L2) will cause increasing in horizontal displacement by (66.7%) and when the impact load increases from (15) kN to (50) kN (from C1L1 to C1L3) this will lead to increasing in horizontal displacement by (391%).

When the load is applied at both sides of the column (C2) as shown in **Fig.10** for node (N11) it is seen that the increase in the impact load from (15) kN to (25) kN (from C2L1 to C2L2) will cause increasing in horizontal displacement by (120%) and when the impact load increases from (15) kN to (50) kN (from C2L1 to C2L3) this will lead to increasing in horizontal displacement by (409%).

By comparing the results in **Fig.9** and **Fig.10** it appears that the maximum horizontal displacement increases by (139%), (208%), and (147%) respectively as compared with C1 and C2.

The vertical displacements due to loading cases at time equals to (0.05) sec are shown in **Fig.11** and **Fig.12** for columns C1 and C2 respectively. The vertical displacement means the displacement is along y-axis and is called (Uy). From these figures it's obvious that column behavior goes in five parts for all load cases. The first part starts from the base of column (N1) to the level of (N7) where there is gradual increase in displacement with height. The second part represents the zone from (N7) to (N9) where there is a sharp change in vertical displacement with increasing the height. The third part of the curve starts from (N9) to (N11) where this nodes represents the cross beam over two parts of column at level (from 9240 to 10050) mm, where the upper and lower faces of the cross beam move in the same pattern due to high flexural rigidity of cross-beam. The fourth part covers the region from N11 to N12 where there is a decrease in vertical displacement value with the distance towards the upper end, and this is due node N11 undergoes flexural and axial loads at the same time while node N12 is free from load and that leads to combined effect which controls this behavior. The fifth part starts from N12 to N13 where there is no change in the displacement value as no load applied to this part of the column.

By comparing the results at **Fig.11** for node (N11) it is seen that by increasing the impact force from (15) kN to (25) kN (from C1L1 to C1L2) will cause an increase in vertical displacement by (64.7%) and when the impact load increases from (15) kN to (50) kN (from C1L1 to C1L3) this will lead to an increase in the vertical displacement by (264.7%).

When the load is applied to both sides of column (C2) as shown in **Fig.12** for node (N11), it is seen that by increasing the impact load from (15) kN to (25) kN (from C2L1 to C2L2) will cause increasing in vertical displacement by (76%) and when the impact load increases from (15) kN to (50) kN (from C2L1 to C2L3) this will lead to an increases in the vertical displacement by (281%).

From comparing the results in **Fig.11** and **Fig.12** it appears the maximum vertical displacement increases by (150%), (172%), and (172%) respectively as compared with C1 and C2.

Fig.13 and **Fig.14** show the values of residual horizontal displacement of columns C1 and C2 respectively. it appears that no residual displacements (horizontal and vertical) exist for load cases C1L1, C1L2, C2L1, and C2L2 which means full elastic behavior is achieved for these columns, while only some residual horizontal displacement is noticed along column (although it is very small) for C1L3 and C2L3, which means some cracks occurs at the column.

Two-leg concrete columns have large stiffness compared to regular normal concrete column, where the link member that connects the two branches reduces the unbraced length of each part of column.

Fig.15 and **Fig.16** show variation of horizontal displacement along column at the link between two branches of column for C1 and C2 respectively at time equals to (0.05) sec., and as comparing these figures it appears that the horizontal displacement of these link members shows approximately linear variation with the height and also with the amount of impact load. This is due to large rigidity of these members. In addition, the applied load is relatively small compared with the capacity of the structure.

Fig.18 and **Fig19** show variation of vertical displacement along column at link between two branches of column C1 and C2 respectively at maximum load at time equals to (0.05) sec. and by comparing these results, it appears that the vertical displacement of link member shows approximately linear variation with the height and shows the displacement decreases with increasing the height, from studying data, it is shows that no vertical displacement is recorded for columns C1L1, C1L2, C2L1, and C2L2. The reason of this behavior is due to position of link member in the center of the column where one branch resists the compression forces and the other resist the tension forces if exist. **Fig.19** shows the value of residual horizontal displacement of link between two branches column for C2. It appears that no residual displacement exists for load cases of columns C1L1, C1L2, C1L3, C2L1, and C2L2 which means full elastic behavior is achieved for these columns, while some residual displacement is noticed along column C2L3 (although it is very little), which means some cracks occur in column.

4.1 Maximum Displacement

From **Figs**.**9, 10, 15**, and**Fig.16** it appears that the maximum horizontal displacement occurs at the crown of column (N13) and this part of the structure is the most critical in this type of column because the section returns to normal shape (square or rectangular shape stand alone as cantilever). Furthermore, this part of column usually carries the weight of the roof which consists of vertical load due to dead load in addition to horizontal force due to wind load. And from **Figs. 11, 12, 17,** and **Fig.18** it appears that the maximum vertical displacement occurs at (N8) at level (8240 mm). **Fig.20** and **Fig.21** show maximum horizontal displacement for the columns C1 and C2 respectively. While **Fig.22** and **Fig.23** show maximum vertical displacement for the column at C1 and C2 respectively. The horizontal displacement at the crown of the column is more than the horizontal displacement at location of applied load. This is because rotation of cross beam that connects two branches of column at level (9240 mm) which leads to additional movement at upper part of the column although no load was applied on it.

4.2 Variation of Displacement with Time

Maximum horizontal displacement of the columns C1 and C2 occurs at node (N13) while maximum vertical displacement occurs at node (N8).

Fig.24 and **Fig**.**25** show variation of the horizontal displacement with time at (N13) for columns C1 and C2 respectively, while **Fig.26** and **Fig.27** show variation of vertical displacement with time at (N8) for columns C1 and C2 respectively.

Examination of **Figs. 24, 25, 26** and **27** show similar behavior in general, the horizontal displacement is equal to zero at time zero as no load exists. Since a triangle load function is used to applied impact force with peak point in (0.05 sec), the horizontal displacement increases but this increment is smooth in columns C1L1 and C1L2 while it takes sharp shape in column C1L3 until reaching maximum value at (0.05 sec). After that as the load decreases until it reaches zero at (0.1 sec) the horizontal displacement is reduced in sharp manner till it reaches zero in (0.06-0.08) sec this is due to large stiffness of this type of column which absorbs all impact energy.

Studying the data obtained from finite element analysis for this type of columns it is observed that no displacement is recorded in Z-direction; therefore, these values will be ignored.

5 .CON LUSIONS

The following conclusions are drawn from the evaluation of analysis of the concrete columns with side openings model under the effect of the impact of regular gantry cranes loads:

1. Horizontal displacement increases with the height of the column in approximately linear pattern up to the position of major cross beam for all loading values.
2. Under large impact load (C1L3 and C2L3), the upper part of the column shows excessive horizontal movement, so these parts require special consideration in design in order to carry additional moment resulting from load eccentricity.

3. Investigation of the load-horizontal displacement curves shows proportional relationship between applied loading and resulting displacements.
4. After removing the loading, no effect appears for horizontal displacement for all loading values except (C1L3 and C2L3) which indicate concrete cracking at some regions along column height.
5. The link members which connect the branches of the column reduce the unbraced length of each part and prevent buckling failure of columns.
6. After removing the loads no effect appears for the vertical displacement along Y-axis.
7. Horizontal displacement in Z-axis equal zero for all cases of loading, as no load applied in that direction and volumetric changes are negligible in that direction.
8. By comparing the results for columns C1 with C2 it appears that the maximum horizontal displacement increases by (139%), (208%), and (147%) respectively.

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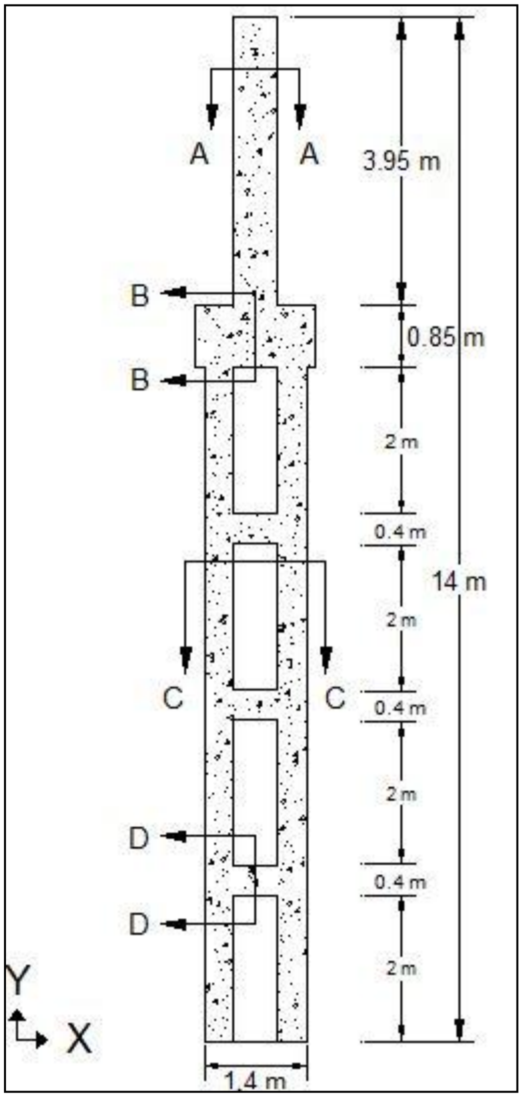


Figure 1. Location of sections along column.

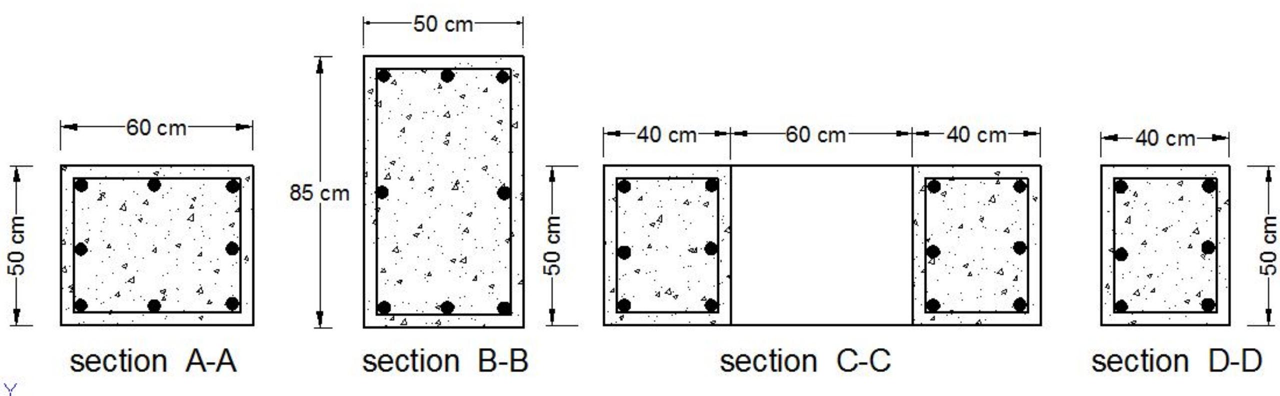


Figure 2. Different sections of the selected column.

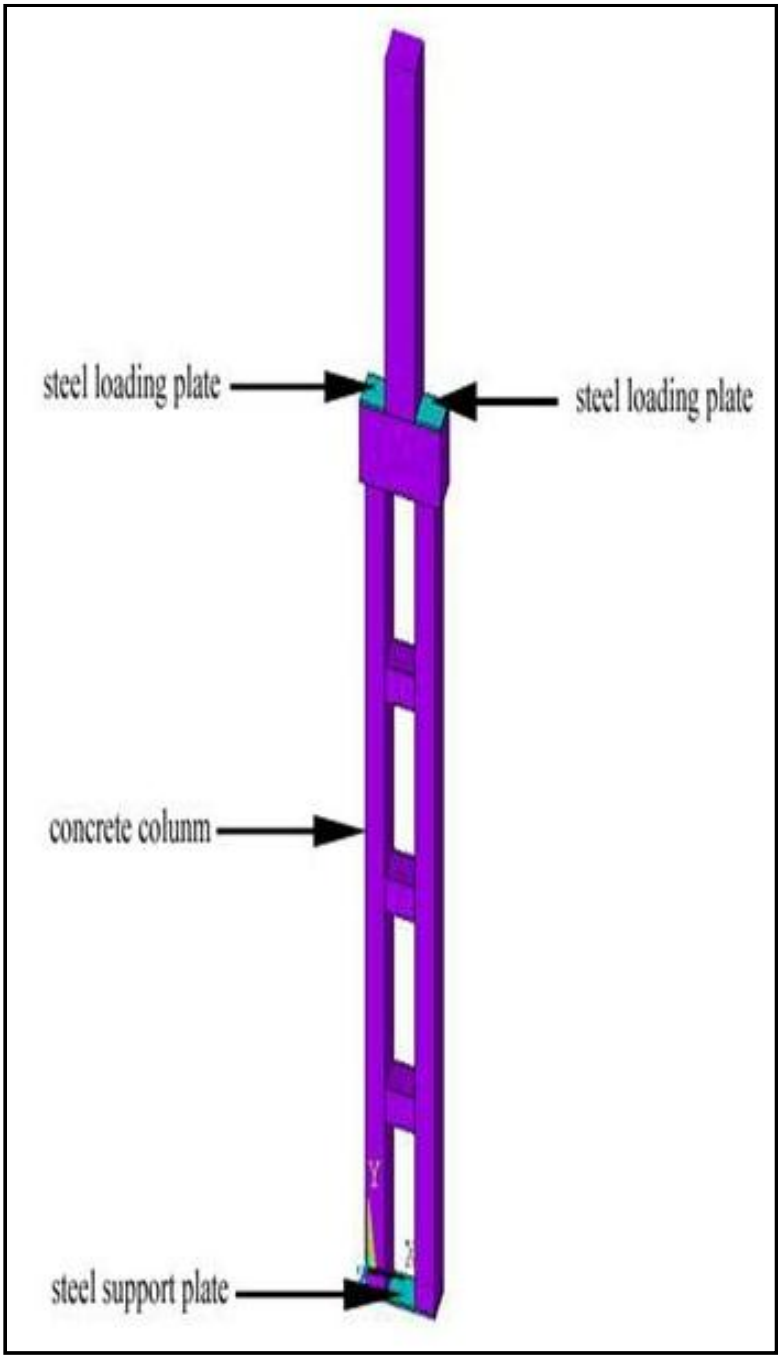
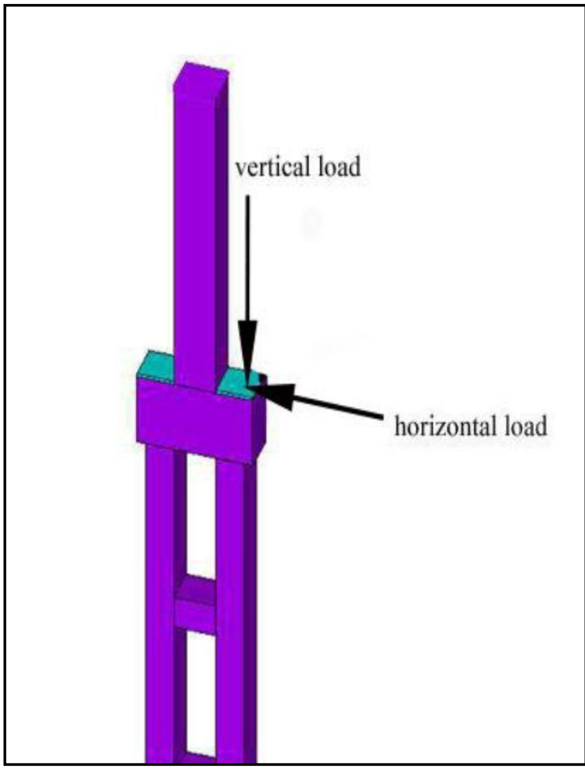


Figure 3. Volumes created in ANSYS**.**



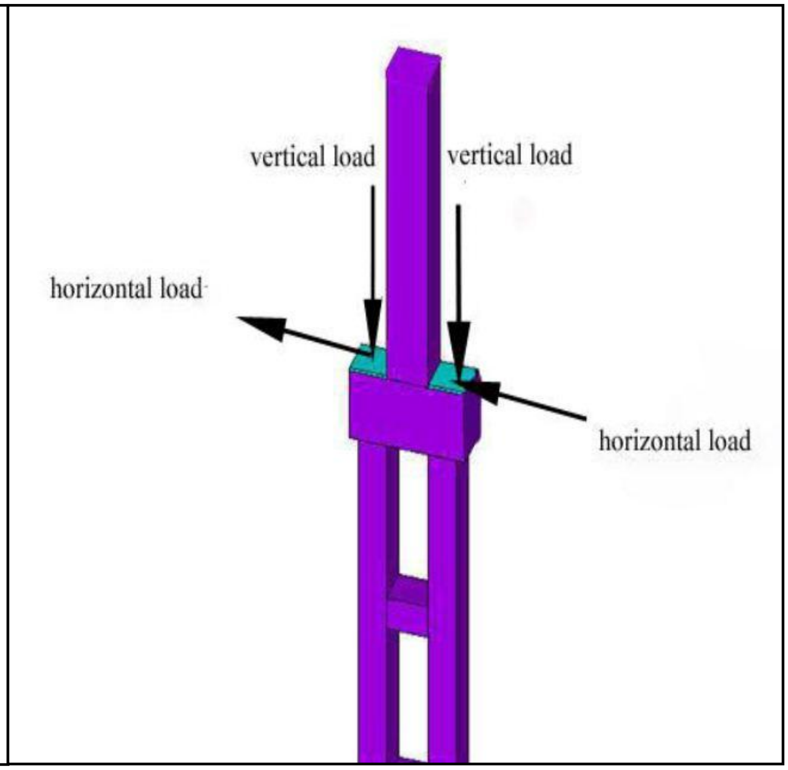


Figure 4. First load case (C1).

Figure 5. Second load case (C2).

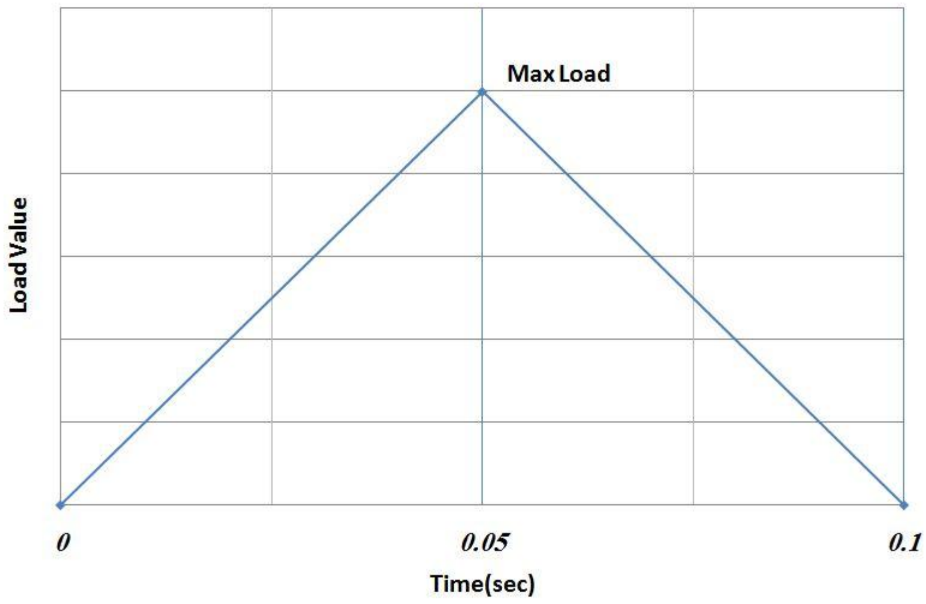


Figure 6. Variation of load with time**.**

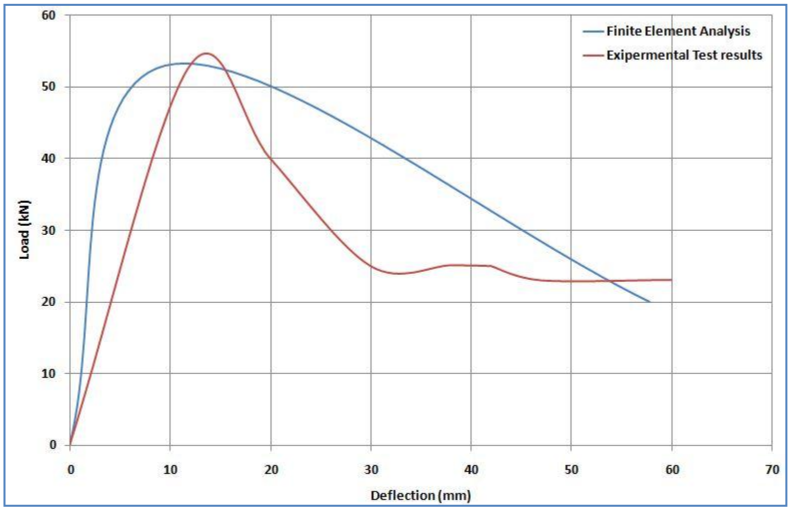


Figure 7. Load-deflection curves for verification example.

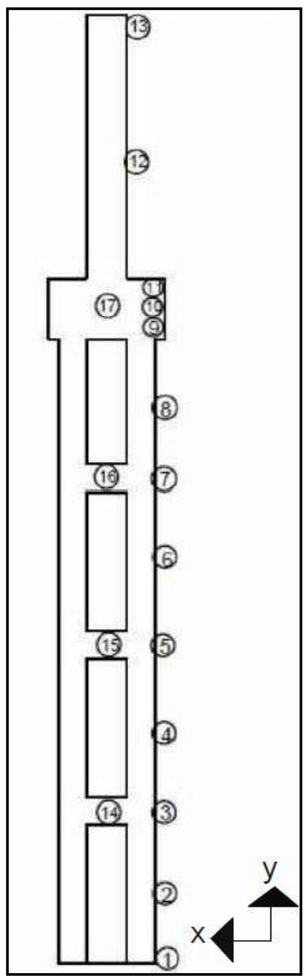


Figure 8. Locations of nodes where the results are recorded.

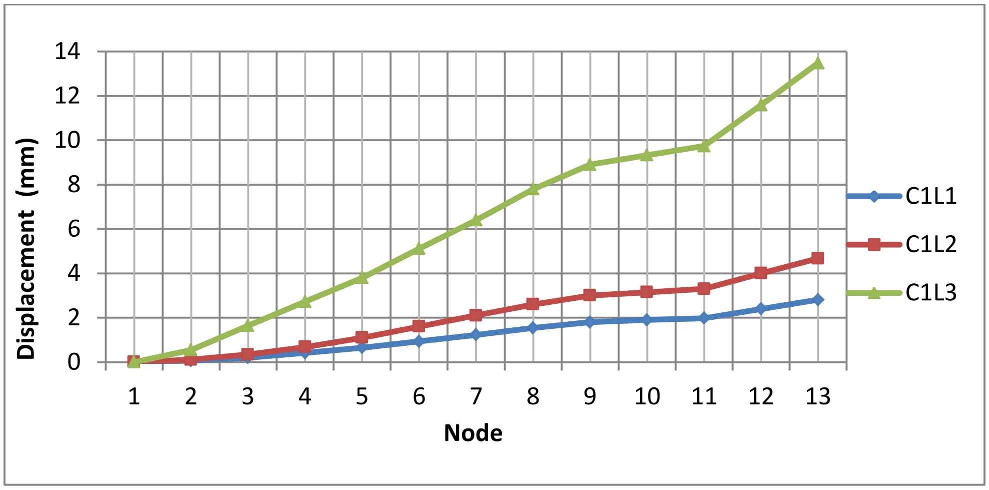


Figure 9. Horizontal displacements along column C1.

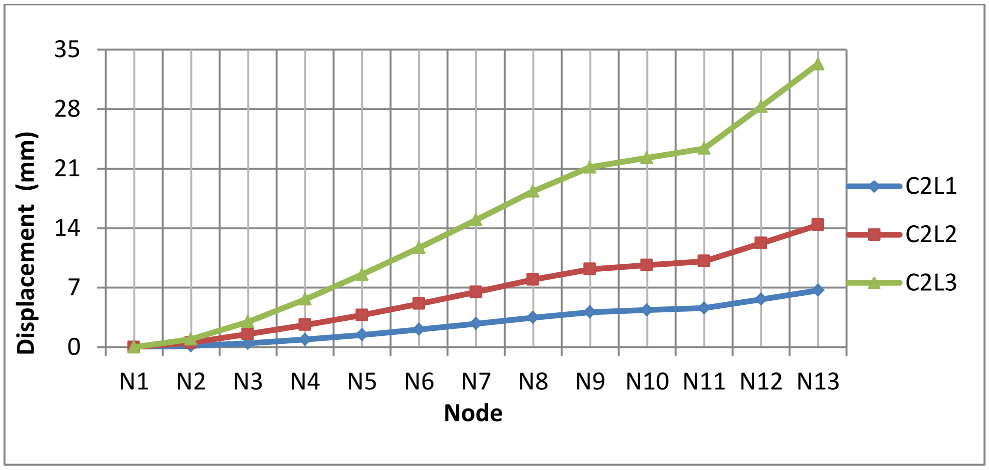


Figure 10. Horizontal displacements along column C2.

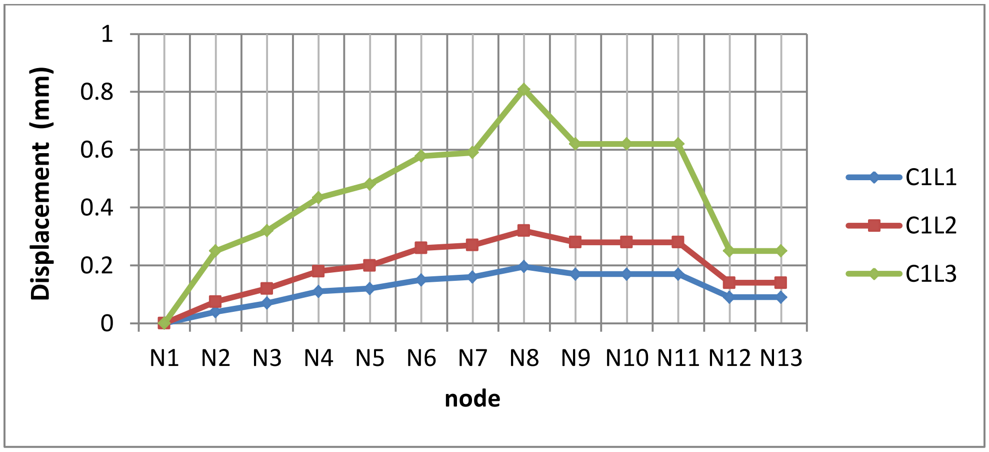


Figure 11. Vertical displacements along column C1.

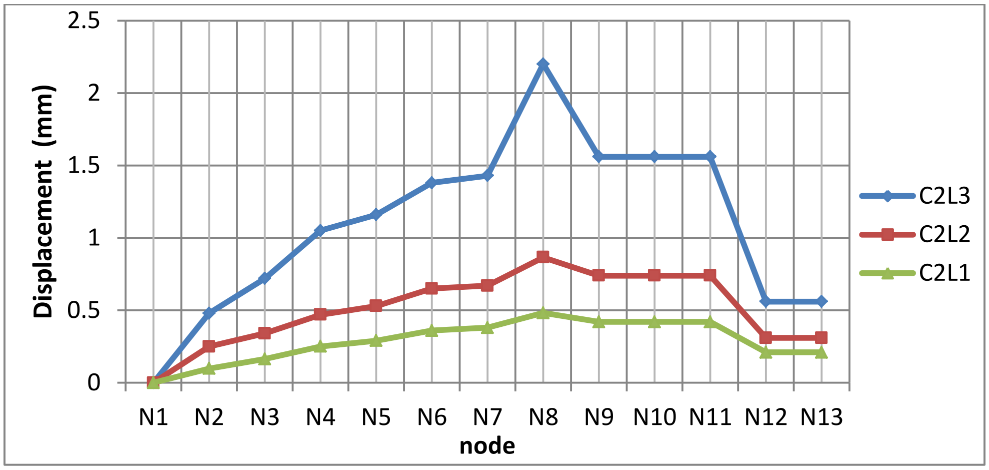


Figure 12. Vertical displacements along column C2.

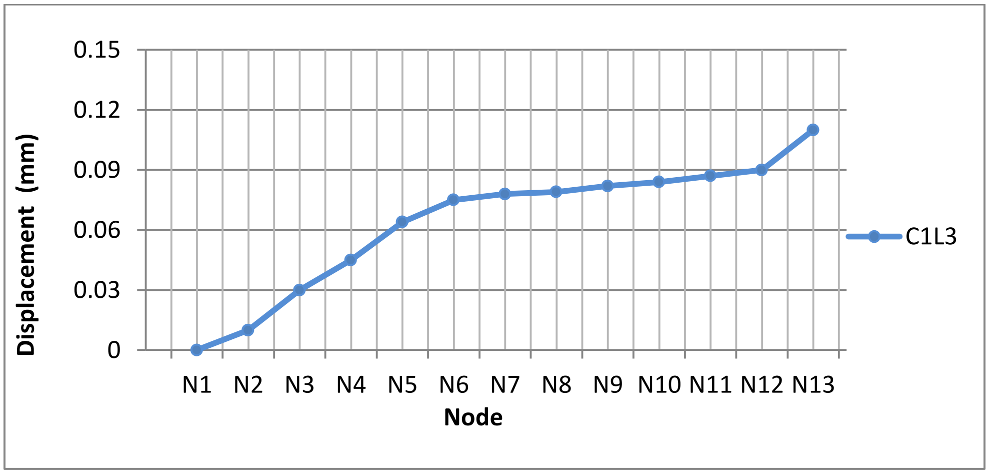


Figure 13. Residual horizontal displacements along column C1

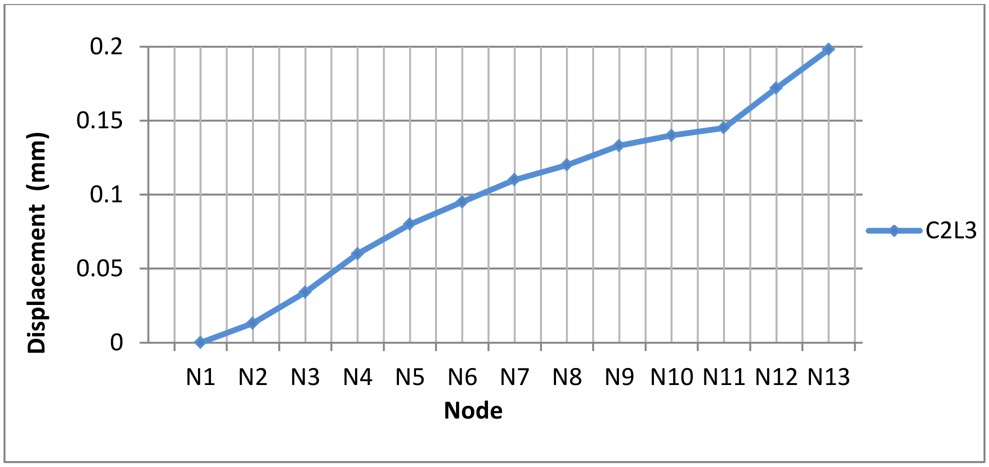


Figure 14. Residual horizontal displacements along column C2.

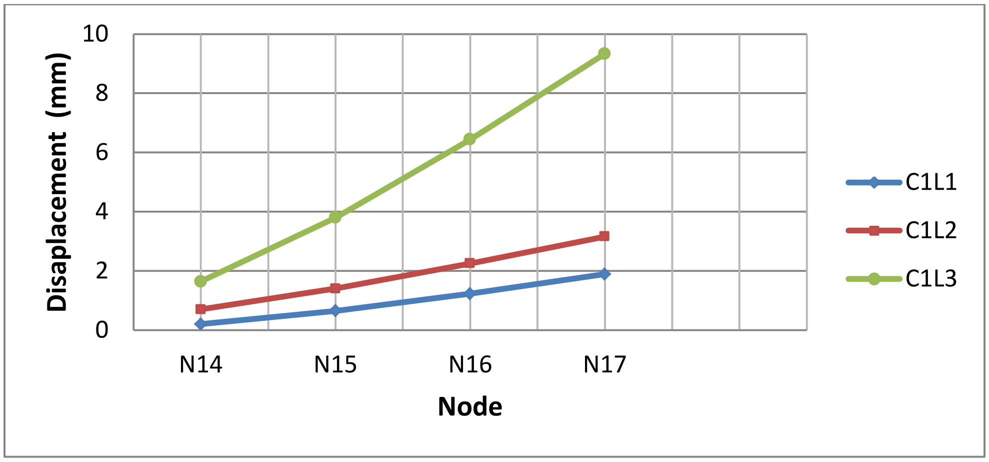


Figure 15. Horizontal displacements at the link between two branches of column C1.

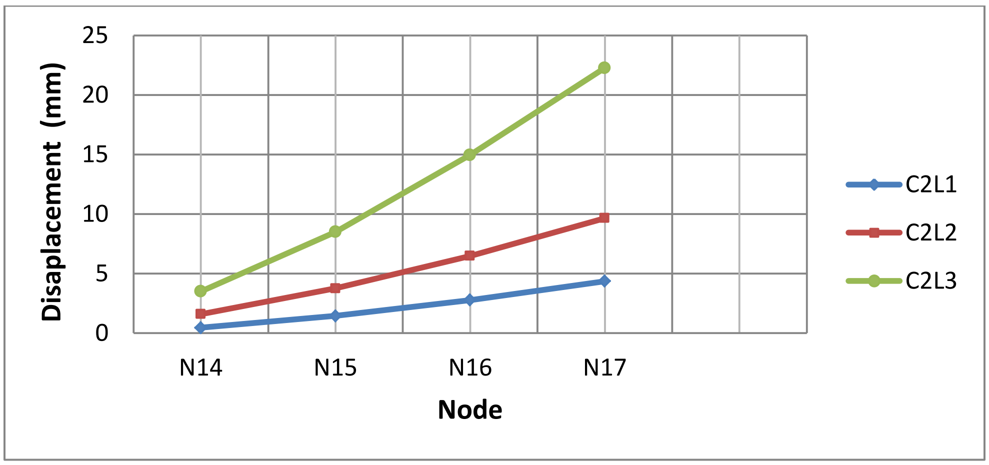


Figure 16. Horizontal displacements at the link between two branches of column C2.

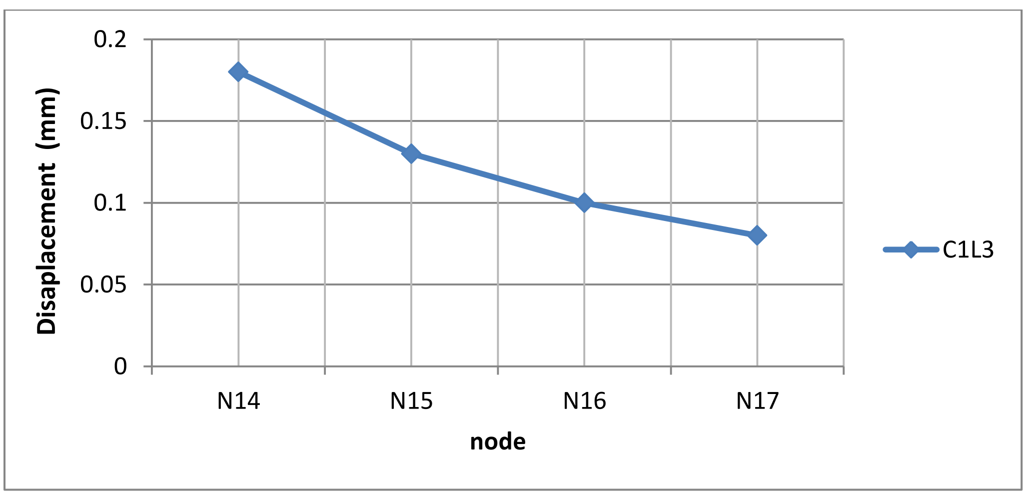


Figure 17. Vertical displacements at the link between two branches of column C1.

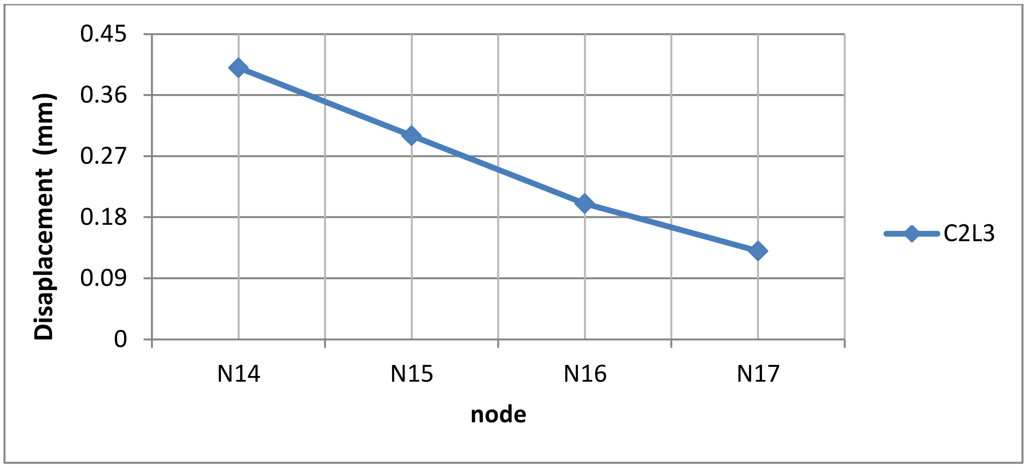


Figure 18 .Vertical displacements at the link between two branches of column for C2.

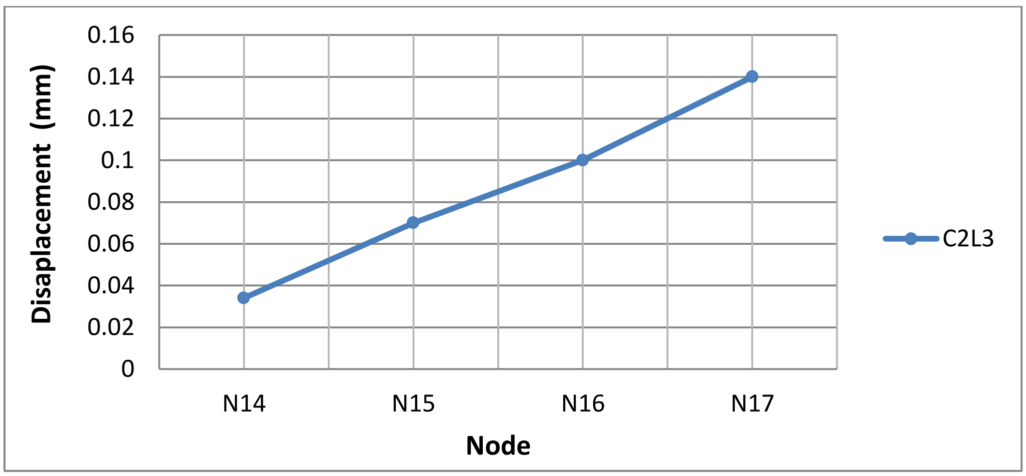


Figure 19. Residual horizontal displacements at the link between two branches of column for C2.

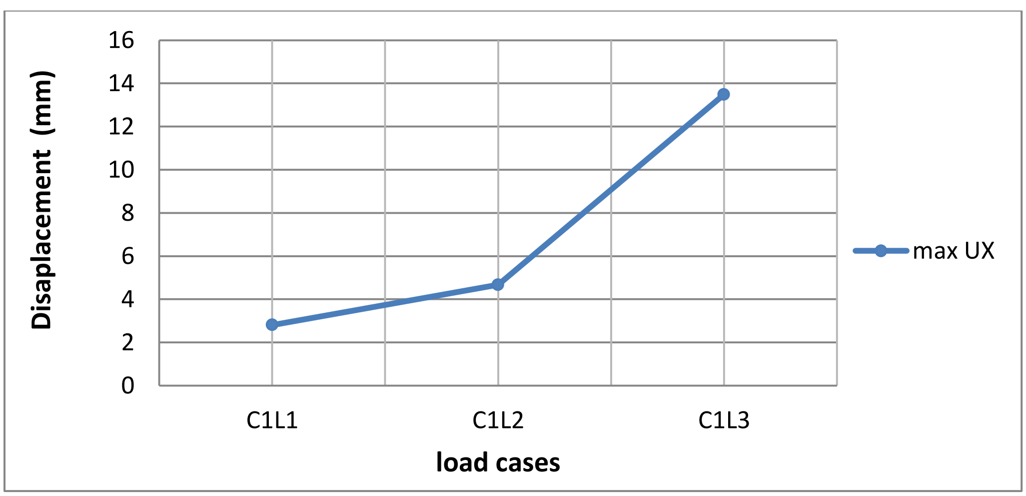


Figure 20. Maximum horizontal displacements at N13 for column C1.

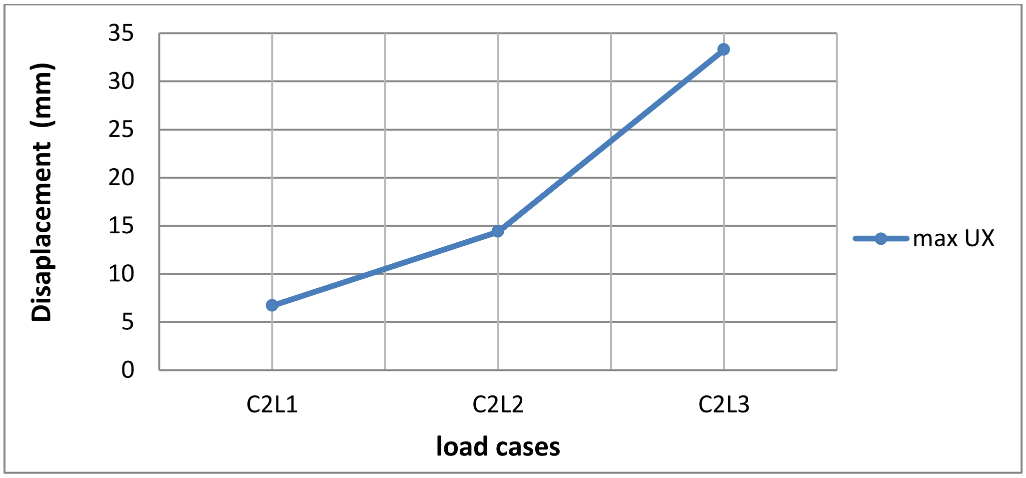


Figure 21. Maximum horizontal displacements at N13 for column C2.

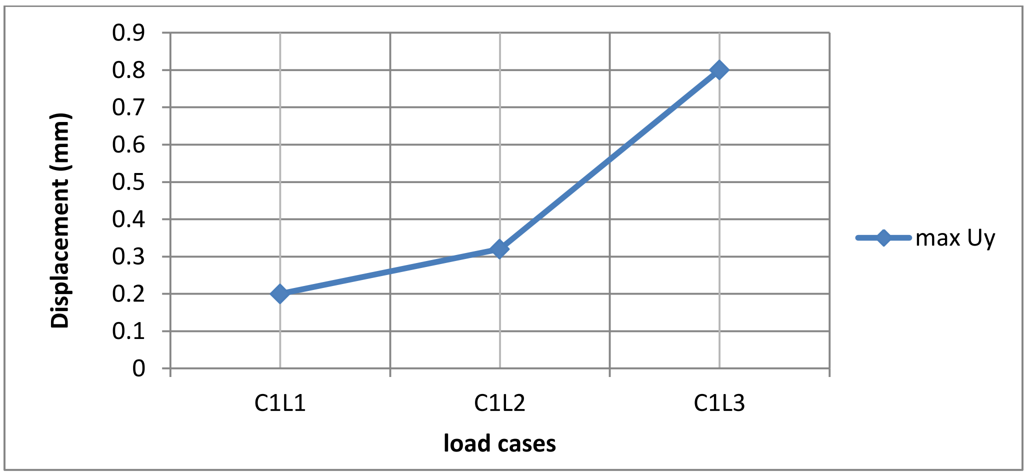


Figure 22. Maximum vertical displacements at N8 for column C1.

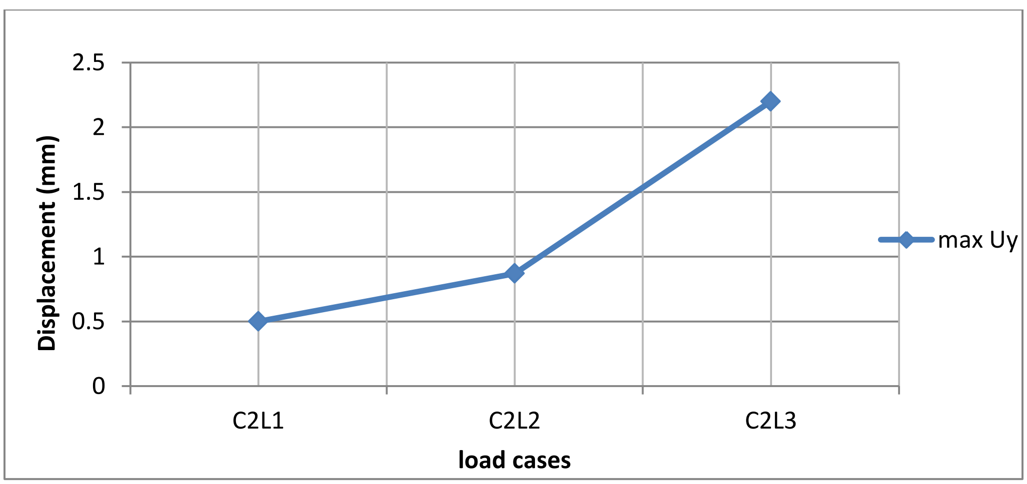


Figure 23. Maximum vertical displacements at N8 for column C2.

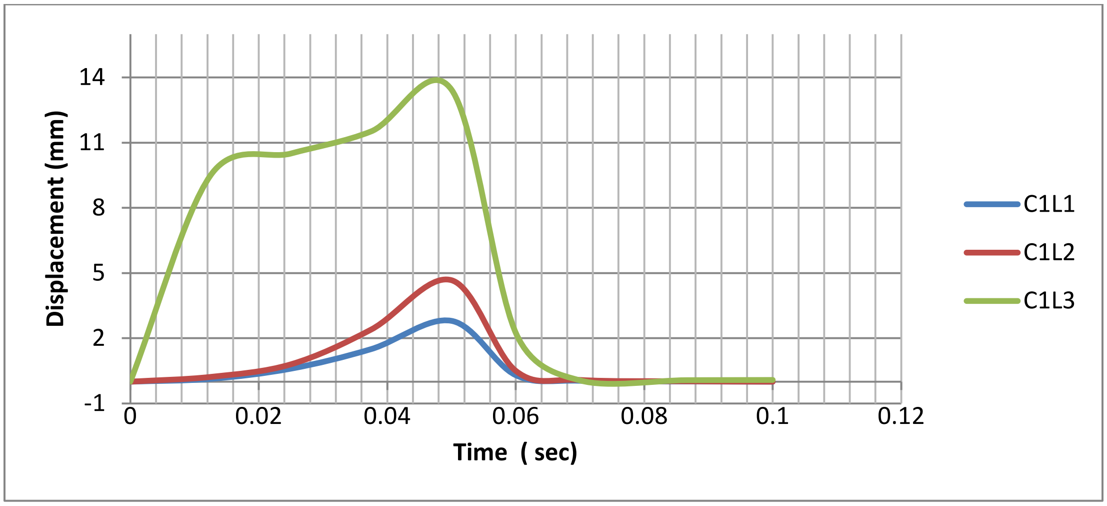


Figure 24. Variation of Ux with time at N13 for column C1.

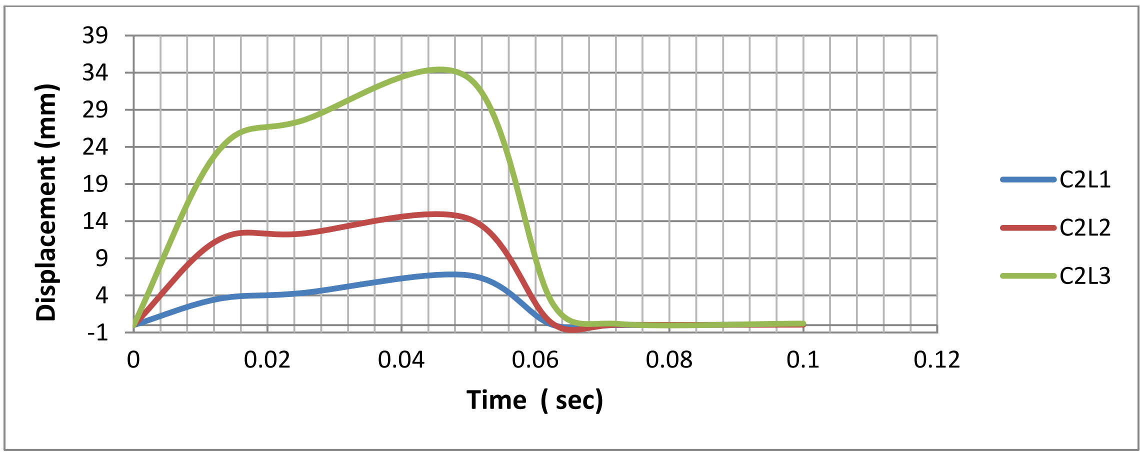


Figure 25. Variation of Ux with time at N13 for column C2.

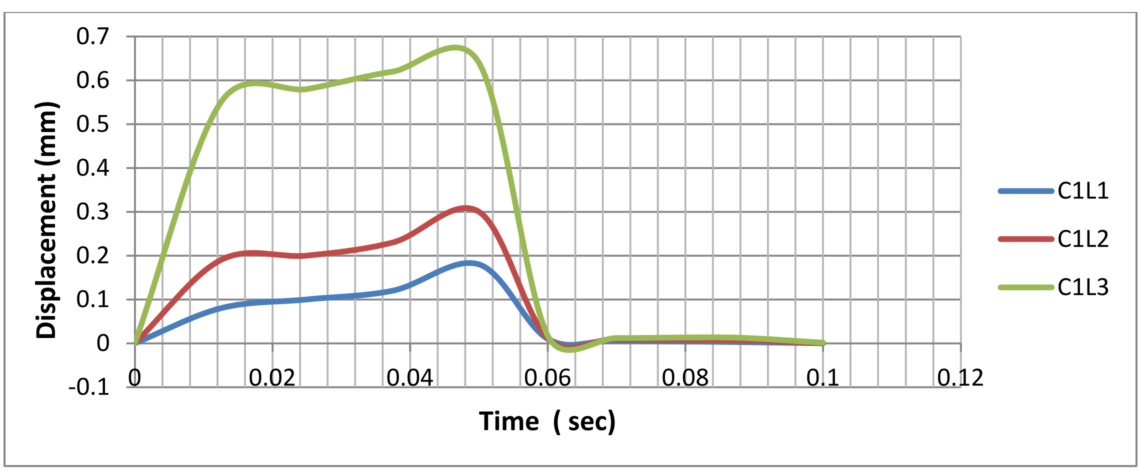


Figure 26. Variation of Uy with time at N8 for column C1.

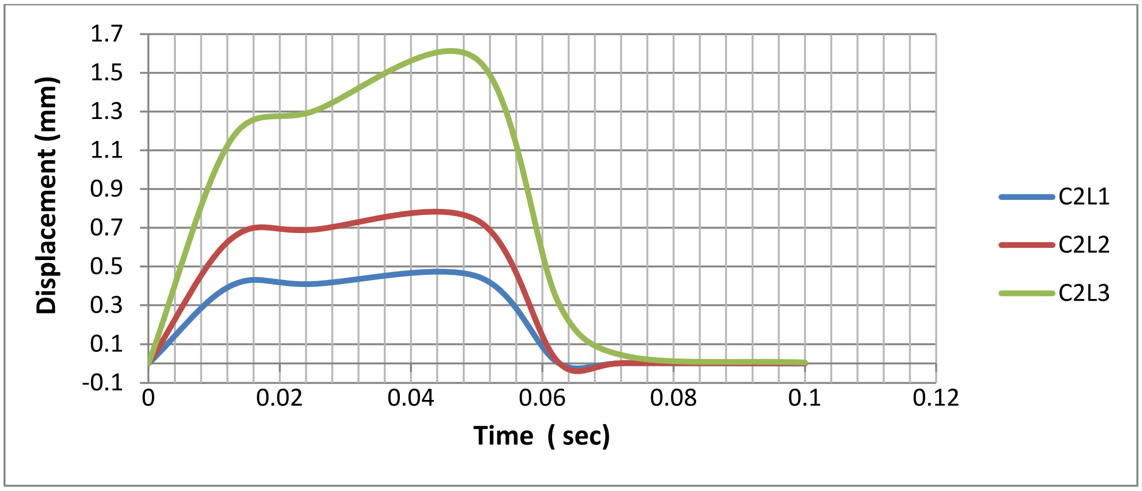


Figure 27 Variation of Uy with time at N8 for column C2.