Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (41) No. (3) July, 2019

# Effect of vertical opening in the shear region of reinforced concrete beams

**1-Prof .Dr.Abo El Wafa El Thakeb, 2- Prof .Dr Ahmed Gomaa Asran, 3- Dr.Mohamed Abd El-Aziam, 4- Eng. Hihsam Zakaria Traad**
(1,2,3) Civil Eng.Dep. Faculty of Eng. – al Azhar Univirsty
(4) M.E, Civil Eng.2014. Higher Technological Instiute

**ملخص البحث:**
تحتوى الأبنية الخرسانية على العديد من شبكات القنوات الرأسية ضرورية لاستيعاب الخدمات الأساسية مثل الإمدادات الرئيسية الكهربائية والهاتف وشبكة الكمبيوتر. عادة ، يتم وضع هذه القنوات في الكمرات الخرسانة المسلحة المحيطة بسلالم المبنى. و تؤدي الفتحات في الكمرات إلى تغيير سلوك الكمرة البسيطة إلى سلوك أكثر تعقيدًا. نظرًا للتغيرات المفاجئة في مقطع الكمرة نتيجه وجود هذة الفتحات الحاده، فإن الزوايا الحاده تخضع لتركيز عالي من الضغط قد يؤدي إلى تشقق غير مقبول من وجهات النظر البنائية و الى خفض صلابة الكمره و نتيجة ما سبق تؤدي الى الصلابة المنخفضة للكمرة و إلى زيادة الترخيم تحت حمل الخدمة ، وقد تتأثر قوة هذه الكمرة وقابلية استخدامها للخدمة بشكل خطير. هذا البحث تحتوى على تأثيرو سلوك الكمرات التي تحتوي على فتحات عمودية تحت اجهاد القص.

## Abstract
In the construction of buildings, a network of vertical ducts is necessary to accommodate essential services like electrical main supply, telephone and computer network. Usually, these ducts are placed in reinforced concrete beams surrounding the stairs of the building, as a result, that openings in beams change the simple beam behavior to a more complex one. Due to abrupt changes in the sectional configuration, opening corners are subject to high stress concentration that may lead to cracking unacceptable from aesthetic and durability viewpoints. The reduced stiffness of the beam may also give rise to excessive deflection under service load, the strength and serviceability of such a beam may be seriously affected. In this paper, beams containing several vertical openings to give a review on the behavior of beams with openings under shear.

**Keywords**
Reinforced concrete beam; vertical opening; shear; experimental; design Codes.

## 1. Introduction
A beam resists loads primarily by means of internal moments, *M*, and shears, *V*. In the design of a reinforced concrete member, flexure is usually considered first, leading to the size of the section and the arrangement of reinforcement to provide the necessary moment resistance. Limits are placed on the amounts of flexural reinforcement which can be used to ensure that if failure was ever to occur; it would develop gradually, giving warning to the occupants. The beam is then proportioned for shear. Because a shear failure is frequently sudden and brittle the design for shear must ensure that the shear strength equals or exceeds the flexural strength at all points in the beam. The manner in which shear failures can occur varies widely with the dimensions, geometry, loading, and properties of the members. For this reason, there is no unique way to design for shear, [1]. Also many researches have been working on horizontal opening at beams to get unique shear design but the vertical opening get ignored, to the author's knowledge, in the researches so this paper describe a research for the vertical openings to obtain the shear effect by three loading setups for long, medium and short shear span.

## 2. Experimental Program

2.1 Description of specimens

Total of ten beams specimens were grouped in four groups showed in figure 1 and detailed in table 1as follows:

- Control beam. Includes one beam with (Lo=300mm, bo =50mm), with 600 mm span between points two loads making the shear zone 600 mm.
- Group 1 (GS) – ( short shear span ) Includes three beams with constant parameters except the length of opening Lo equal to 200,300 and 400 mm, with 1000 mm span between point two loads making the shear zone 400 mm .
- Group 2 (GM) – ( medium shear span ) Includes three beams with constant parameters except the length of opening Lo equal to 200,300 and 400 mm ,with 600 mm span between point two loads making the shear zone 600 mm .
- Group 3 (GL) –( long shear span ) Includes three beams with constant parameters except the length of opening Lo equal to 200,300 and 400 mm ,with 200 mm span between point two loads making the shear zone 800 mm .

Which:

- Lo is the length opening
- bo is the width of opening

Table 1

| SERIES | Beam no. | b*t mm | web rein-forcement | OPENING | | Shear zone (a) |
|---|---|---|---|---|---|---|
| | | | | Lo/bo | Po F. CENTER | |
| control beam | | 200*300 | 3Y8 | 6 | 300 mm | 600 mm |
| Group.1 | GS1 | 200*300 | 9Y8 | 4 | 200 mm | 400 mm |
| | GS2 | 200*300 | 9Y8 | 6 | 200mm | 400 mm |
| | GS3 | 200*300 | 9Y8 | 8 | 200 mm | 400 mm |
| Group.2 | GM1 | 200*300 | 9Y8 | 4 | 300 mm | 600 mm |
| | GM2 | 200*300 | 9Y8 | 6 | 300 mm | 600 mm |
| | GM3 | 200*300 | 9Y8 | 8 | 300 mm | 600 mm |
| Group.3 | GL1 | 200*300 | 9Y8 | 4 | 400 mm | 800 mm |
| | GL2 | 200*300 | 9Y8 | 6 | 400 mm | 800 mm |
| | GL3 | 200*300 | 9Y8 | 8 | 100 mm | 800 mm |

The bottom longitudinal reinforcement for all beams are two bars of diameter 16 mm and upper reinforcement 2 bars with diameter 12 mm , the depth ( d) for all beams 267 mm.

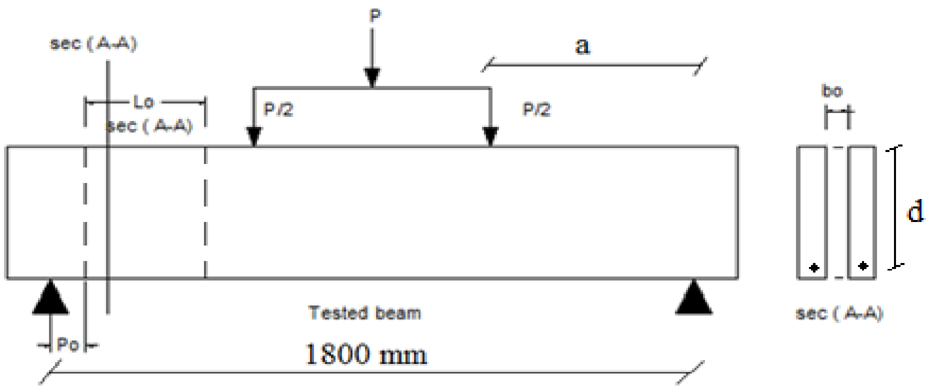


Figure 1 beam layout

### *2.2 Materials*

For concrete, maximum coarse aggregate size was 10 mm. and maximum fine aggregate size was 5 mm. Portland cement was used in the concrete mix. Table (2) gives the concrete mix design used for the test specimens of this experimental program.

Table (2), Design of the concrete mix

| Component | Mass ($kg/m^3$) | Mass/Mass of cement |
|---|---|---|
| Cement | 450 | 1 |
| Water | 225 | 0.50 |
| Fine aggregate | 600 | 1.33 |
| Coarse aggregate | 1220 | 2.71 |

Table (3) gives the actual concrete compressive strength, $f_{cu}$, on the testing day represented by the average strength of three standard 150 mm x 150 mm cube for every specimen. The flexural reinforcement of the tested specimens as well as the longitudinal reinforcement consisted of high grade steel of diameters 12 and 16 mm. The beam stirrups were of normal mild steel 8 mm diameter. The tests were carried out in the reinforced concrete laboratory, at Al-Azhar University.

Table (3), Concrete compressive strength of test specimens

| Test specimen | Age at testing (days) | $f_{cu}$ ($N/mm^2$) | | | Average compressive strength $f_{cu}$ ($N/mm^2$) |
|---|---|---|---|---|---|
| | | Cube 1 | Cube 2 | Cube 3 | |
| Control & G1 | 32 | 39.2 | 42.7 | 40.3 | 40.7 |
| G 2 & G 3 | 35 | 39.4 | 41.8 | 40.5 | 40.6 |

### *2.3 Test setup and Instrumentation*

The layout and dimensions of the testing frame is shown in figure (1). The specimen were tested under monotonic increasing load through a hydraulic jack of 1000 kN capacity. The applied load is measured via a Load cell of a 750 kN capacity. The tensile strains of the flexural reinforcement as well as the compressive strains of the concrete were measured by using strain gauges. Two strain gauges were installed on the longitudinal bars at mid shear and mid span. The maximum deflection of the specimens was measured through LVDTs installed at the bottom of the specimens. A four channel data acquisition system was used to record the loads, strains, and deflection of the tested specimen. Data acquisition system adjusted to record 5 reading per second from all the attached instruments. Vertical load was applied incrementally until failure load. Figure (3) shows the test setup. The flexural reinforcement, stirrups and locations of the tensile strain gauges are shown in figure (2).

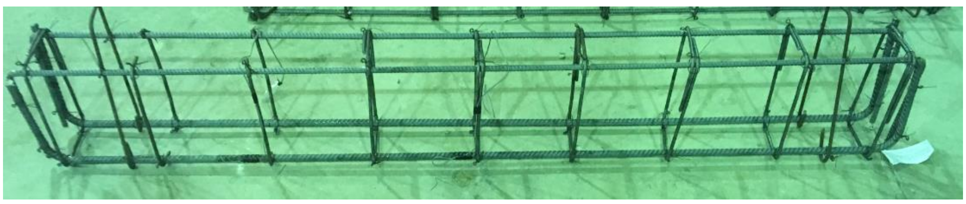

Figure 2 longitudinal reinforcement and stirrups

Figure 3 test setup

**3. Experimental Results**

3.1Crack patterns and failure modes

Figures (4) to figure (13) show the failure pattern of the tested beams. Initial cracks and ultimate loads of the beams are listed in Table (4) further more table (5) lists failure modes for tested beams. Initially, closely vertical cracks appeared in the mid span region for all specimens. the vertical cracks were of small width and concentrated in the mid span region. However, with further increase of load, the length and width of cracks increased near the support, angles of cracks became shallower and turned diagonal. When load was further increased, the depth of some of the diagonal cracks further increased and crossed into the compression zone of the beam as beam GS2 and GS3, showen in figure 6 and figure 7 respectively, which ultimately caused the failure of the beams as the cracks extended further towards the point of application of loads.

For beams with web reinforcement, the crack pattern has been considerably affected by the percentage of web reinforcement in beam. The number of cracks has been increased but their widths have been decreased. The failure angles have also been reduced.

Figure 4 crack pattern in control beam

Figure 5 crack pattern in GS1

Figure 6 crack pattern in GS2

Figure 7 crack pattern in GS3

Figure 8 crack pattern in GM1

Figure 9 crack pattern in GM2

Figure 10 crack pattern in GM3

Figure 11 crack pattern in GL1

Figure12 crack pattern in GL2

Figure 13 crack pattern in GL2

**Table (4), Ultimate loads, initial crack load for the tested specimens.**

| SERIES | Beam No. | shear Span (mm) | Main steel $A_s$ | $A_s$ ' | Stirrups | $P_u$ (KN) | Deflection (mm) Mid-point | First Crack Load (KN) | FIRST CUTTED STRAIN AT LOAD |
|---|---|---|---|---|---|---|---|---|---|
| **Control** | **GB** | **600** | **2T16** | **2T12** | **3Y8** | **126** | **5.99** | **50** | SHEAR STRAIN 92.3 |
| **G1** | **GS1** | **400** | **2T16** | **2T12** | **9Y8** | **295** | **12.13** | **75** | SHEAR STRAIN 86 |
| | **GS2** | **400** | **2T16** | **2T12** | **9Y8** | **269** | **9.245** | **75** | SHEAR STRAIN 83 |
| | **GS3** | **400** | **2T16** | **2T12** | **9Y8** | **274** | **10.44** | **70** | SHEAR STRAIN 85 |
| **G2** | **GM1** | **600** | **2T16** | **2T12** | **9Y8** | **182** | **8.8** | **65** | UNCUTTED Strain but shear strain is more than mid span |
| | **GM2** | **600** | **2T16** | **2T12** | **9Y8** | **220** | **12.2** | **50** | |
| | **GM3** | **600** | **2T16** | **2T12** | **9Y8** | **192** | **10.12** | **50** | |
| **G3** | **GL1** | **800** | **2T16** | **2T12** | **9Y8** | **141** | **8.3** | **50** | SHEAR STRAIN 83 |
| | **GL2** | **800** | **2T16** | **2T12** | **9Y8** | **174** | **33.6** | **55** | SHEAR STRAIN 85 |
| | **GL3** | **800** | **2T16** | **2T12** | **9Y8** | **160** | **28.3** | **40** | SHEAR STRAIN 89 |

**Table (5), failure mode.**

| SERIES | Beam No. | Observed type of failure | Reason of failure |
|---|---|---|---|
| **control** | GB | sever shear crack without cover splitting out | Shear failure |
| **Group.1** | GS1 | steep and sever shear crack with cover splitting out at opening suddenly | Compression shear failure, due to the point load is too close to support |
| | GS2 | | |
| | GS3 | | |
| **Group.2** | GM1 | steep and sever shear crack without cover splitting out at opening | Shear failure |
| | GM2 | | |
| | GM3 | | |
| **Group.3** | GL1 | multi - intermediate shear crack and flexural cracks without concrete splitting out opening | Shear failure due to the point load at the mid span of beam making flexural behavior mixed with shear behavior |
| | GL2 | multi - intermediate flexural cracks then shear crack at final stage without concrete splitting out opening | |
| | GL3 | multi - intermediate shear crack and flexural cracks without concrete splitting out opening | |

Table (6), percent of losses due to opening

| Beams | | PERCENT OF LOSSES DUE TO OPENING | |
|---|---|---|---|
| | | Pu | % |
| | | KN | % |
| G1 | GS1 | 22.56 | 7.7 |
| | GS2 | 26.56 | 9.1 |
| | GS3 | 24.56 | 8.4 |
| G2 | GM1 | 64.04 | 28.5 |
| | GM2 | 15.64 | 6.9 |
| | GM3 | 40.64 | 18.0 |
| G3 | GL1 | 80.08 | 36.0 |
| | GL2 | 61.08 | 27.5 |
| | GL3 | 66.28 | 29.8 |

## 3.2 Load-maximum deflection relationships

Failure Load and maximum deflection for all test specimens are shown in figure (14) to figure (17).

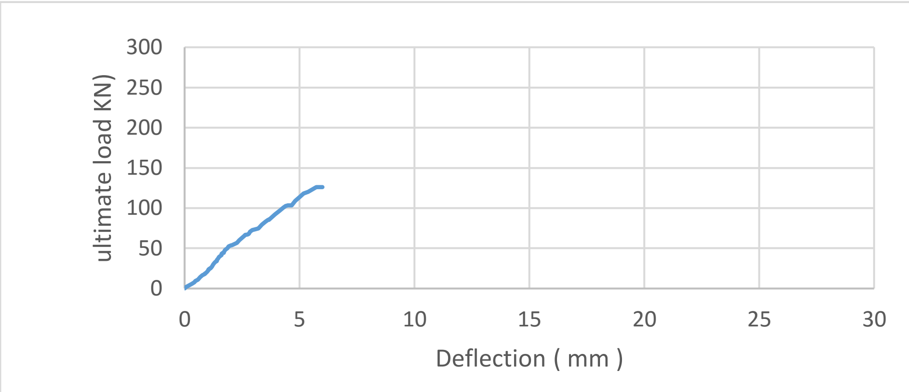


Figure (14) Load – deflection relationship for control beam (GB)

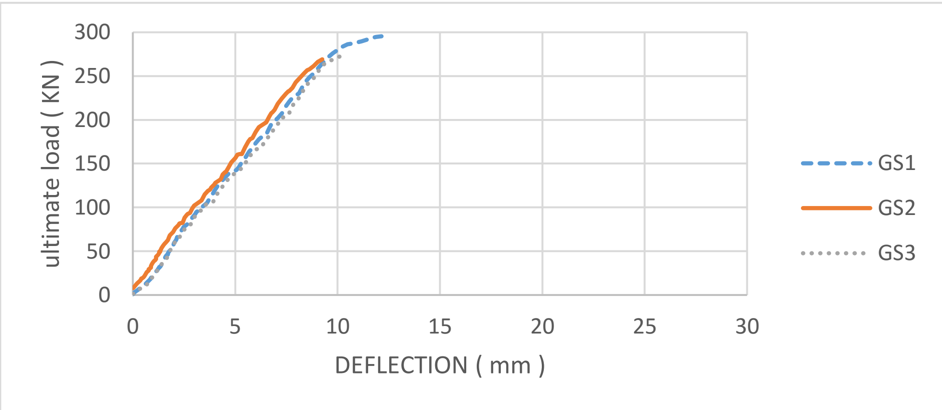


Figure (15) Load – deflection relationship for group 1

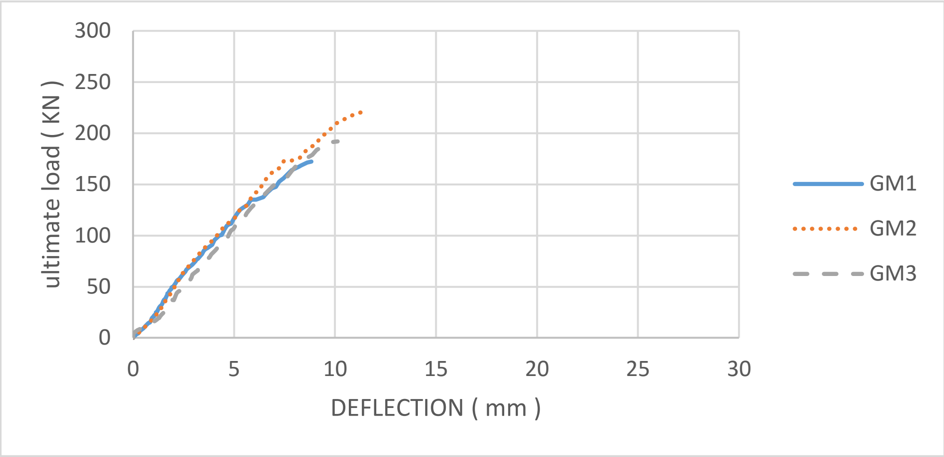


Figure (16) Load – deflection relationship for group 2

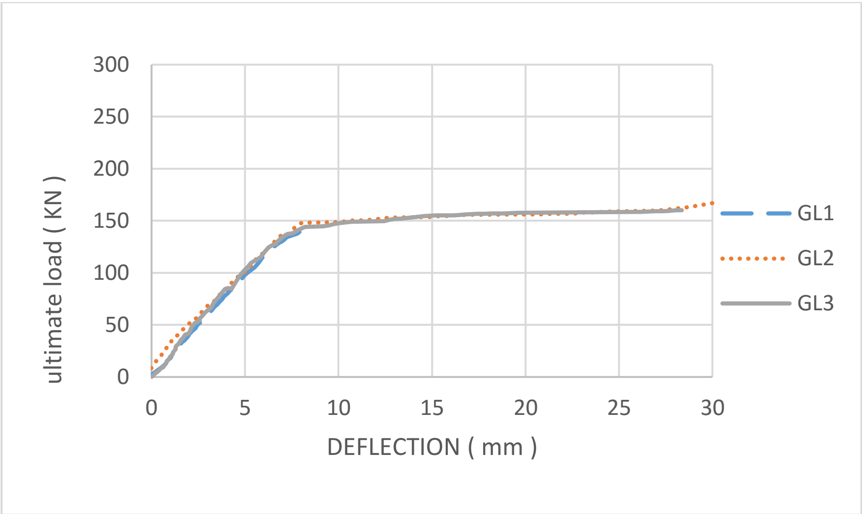


Figure (17) Load – deflection relationship for group 3

## 4. Analysis of Test Results

4.1 The Effect of test variables on cracking and modes of failure of tested beams are listed below:

As shown from test results and figures, it is noticed that:

1. The number of cracks and their widths increased within the increase of opening length. This because the opening length is getting larger than the shear span and taking movements to the mid span.
2. The cracking in mid span increases as the position of opening increases from support. This is because the stress becomes greater in flexural span.
3. The number of cracks and their widths decreased within the increase of opening width and giving sudden crack failure. This because the stress is concentrated in the web of beam in shear zone.

### 4.2 Deflection of the tested beams

Deflection of the tested beams was measured at mid-span for each beam and readings were recorded. Table (4) shows the maximum Values of deflections for each beam. Figures from (15) to (18) show the load-deflection relationship. In the following paragraphs, the effect of different parameters on the load - deflection behavior of the tested specimens is presented.

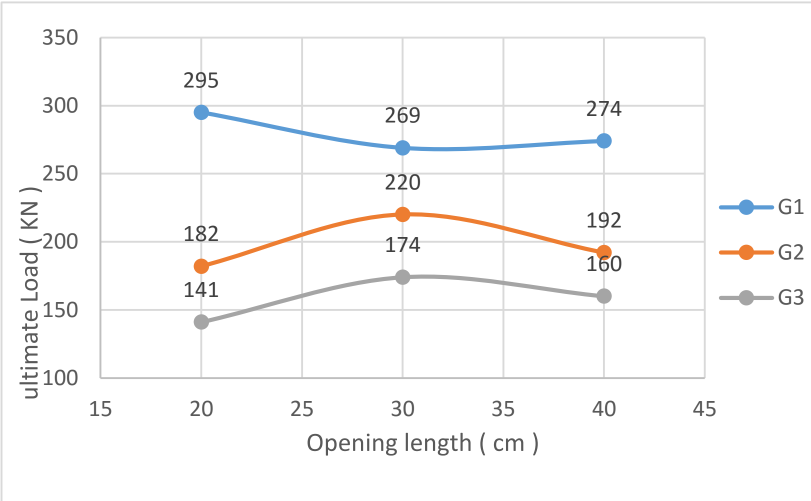


Figure 18 relation between lengths of opening to ultimate load

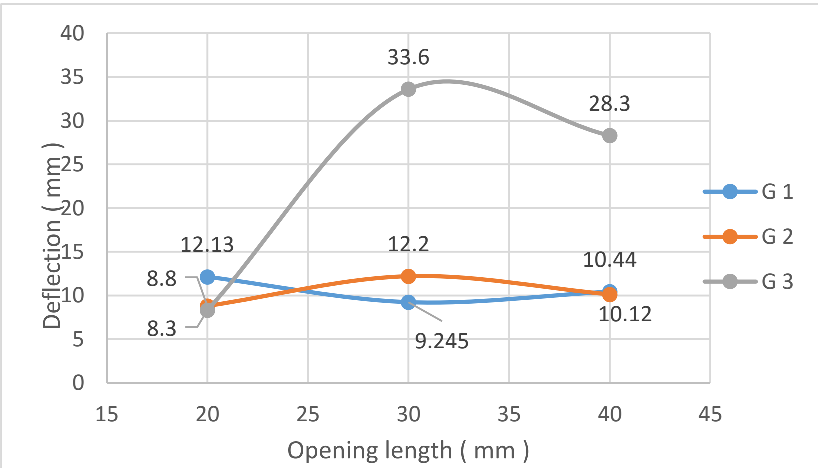


Figure 19 relation between lengths of opening to deflection

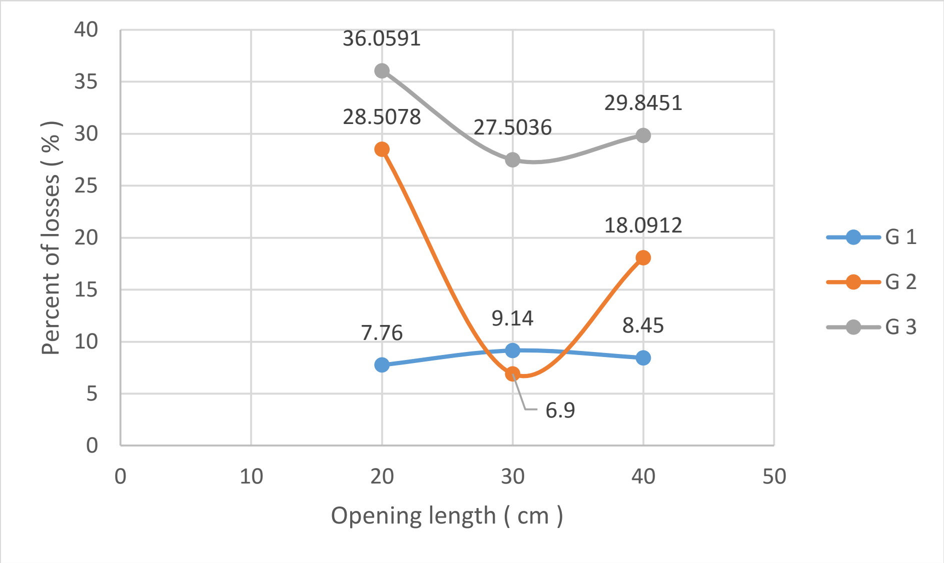


Figure 20 relation between percent of losses to length of opening

## 5. Conclusion

From both experimentally and numerically tested beams specimens the following conclusions can be summarized

1. The dimension of opening in the shear zone have major effect on the beam behavior in shear
2. Beams with openings have length equal to six times width of opening showed typical shear crack distribution.
3. Beams having ratio of opening length to shear zone length ( Lo/a) varying from 0.5 up to 4 showed loss in shear capacity varying from 7% up to 30% when compared to the control beam with no opening.
4. Beams with shear span to depth ratio (a/d=3) undergo higher deflection by 200% when compared to beams with shear span to depth ratio (a/d=1.5).this indicate more ductility for the beams with higher shear to depth ratio.
5. Beams with short span to depth ratio (a/d=1.5) undergo brittle failure compered to beams with higher shear span to depth ratio a/d=3)
6. The ultimate load capacity decreased by 10 % and the deflection increases by 100% with decreasing of loading span between 2 point loads.
7. Percentage of web reinforcement to cross sectional area of opening zone is most effective factor,

- Short span loading ( Group 1 ) , the losses of ultimate load increased with the increase of opening length from 200 mm to 300 mm then the losses decreased by 1 % between the opening length 300 mm and 400 mm and this is due to the increase of the web reinforcement percent to cross section area from 0.2 to 0.3 %.
- Medium span loading ( Group 2) , the losses of ultimate load decreed by 21.5 % with the increase of opening length from 200 to 300 mm this due to the increase of the web reinforcement percent to cross section area increased from 0.3 % to 0.4 % . The losses get higher by 11 % for the next specimen with opening length 400 mm and this due to the decreeing of web reinforcement to cross sectional area from 0.4 to 0.3%.

- Long span loading (Group 3 ) , the losses of ultimate load decreed by 9 %with the increase of opening length from 200 to 300 mm this due to the increase of the web reinforcement percent to cross section area increased from 0.3 % to 0.4 % . The losses get higher by 2% for the next specimen with opening length 400 mm and this due to the decreeing of web reinforcement to cross sectional area from 0.4 to 0.3%.

## References


1. Boyd G. Anderson, “Rigid Frame Failures,” ACI Journal, Proceedings, Vol. 53, No. 7, January 1957, pp. 625–636.
2. Howard P. J. Taylor, “Investigation of Forces Carried across Cracks in Reinforced Concrete Beams in Shear by Interlock of Aggregate,” TRA 42.447, Cement and Concrete Association, London, 1970, 22 pp.
3. Robert Park and Thomas Paulay, Reinforced Concrete Structures, A Wiley-Interscience Publication, Wiley, New York, 1975, 769 pp.
4. ACI-ASCE Committee 426, “The Shear Strength of Reinforced Concrete Members—Chapters 1to 4,” Proceedings ASCE, Journal of the Structural Division, Vol. 99, No. ST6, June 1973, pp. 1091–1187.
5. Jorg Schlaich, Kurt Schaefer, and Mattias Jennewein, “Towards a Consistent Design of Reinforced Concrete Structures,” Journal of the Pre-stressed Concrete Institute, Vol. 32, No. 3, May–June 1987.
6. ACI-ASCE Committee 426, Suggested Revisions to Shear Provisions for Building Codes, American Concrete Institute, Detroit, 1978, 88 pp.; abstract published in ACI Journal, Proceedings,Vol. 75, No. 9, September 1977, pp. 458–469; Discussion, Vol. 75, No. 10, October 1978, pp. 563–569.
7. Michael P. Collins and Dan Kuchma, “How Safe are our Large, Lightly Reinforced Concrete Beams, Slabs, and Footings?” ACI Structural Journal, Proceedings, Vol. 96, No. 4, July–August 1999, pp. 482–490.
8. Z.P. Bazant and J.K. Kim, “Size Effect in Shear Failure of Longitudinally Reinforced Beams,” ACI Journal, Proceedings, Vol. 81, No. 5, April 1984, pp. 456–468.
9. Bazant Z. P., and Kazemi, M.T. (1991). "Size Effect on Diagonal Shear Failure of Beams without Stirrups". ACI Structural Journal, (3), 268-274.
10. CSA Committee A23.3 (2004). "Design of Concrete Structures (CSA A23.3-04).” Canadian Standards Association, Mississauga, 214 pp.
11. Appa, Rao G., and Injaganeri, S.S. (2011). "Evaluation of Size Dependent Design Shear Strength of Reinforced Concrete Beams without Web Reinforcement". Sadhana Journal, June, 36 (3), 393-410.
12. ACI-ASCE Committee 445 on Shear and Torsion. (1998). "Recent Approaches to Shear Design of Structural Concrete". ASCE Journal of Structural Engineering, 124 (12), 1375-1417.