# DEFLECTION OF STRAIGHT AND CAMBERED BEAMS MEASURED DURING FOURTEEN HOURS PER DAY

**Dr. Kanaan Sliwo Youkhanna Athuraia**

## ABSTRACT

Straight and camber beams in portal frames [Footings + Columns + Beams] were studied. Deflection for period of fourteen hours in a day was measured for ten days.

Peak value of deflection within a day is predicted for each one of the beams under a sustained load uniformly distributed.

It is suggested that the load test is to be performed during critical period, within a day, that gives peak deflection.

## الخلاصة

تمت دراسة عتبات مستقيمة ومقوسة (**Camber**) ضمن هياكل حاملة حقيقية [أسس + أعمدة + عتبات]. تم قياس الإنحراف (الأود) لفترة أربع عشرة ساعة باليوم ولمدة عشرة أيام.

تم الحصول على القيمة العظمى (**Peak**) للإنحراف (الأود) ضمن اليوم ولكل عتبة تحت حمل مستمر موزع بالتساوي (**Uniformly Distributed Load**).

يمكن أن نقترح بأن يتم عمل فحص التحميل (**Load Test**) خلال الفترة الحرجة ضمن اليوم والتي تعطي أعظم إنحراف (أود).

**KEY WORDS**

: **camber, deflection, load test, peak, straight.**

## INTRODUCTION

Reinforced concrete has taken its place as one of the most important structural material due to its relatively high compressive strength, durability, adaptability to various forms and its relatively low cost. It, however, has the unfavorable characteristic of relatively low tensile strength.

Reinforced concrete buildings respond quite significantly to changes in loading and environment in addition to the natural laws which govern the behavior of the materials, leading to the inevitable deflection. To the engineer, these movements (deformations) should take an important considerations in ensuring that the structure is safe and will satisfactorily fulfil its purpose.

Arching is the oldest structural method for bridging too long spans. Arches are made of masonry, steel, timber and reinforced concrete.

Introducing some camber (shallow curvature) to flexural members (beams or slabs) may mobilize end restraint forces. Curved flexural members tend to straighten when a load is applied on them under the action of “angular deformation”. This tends to increase the span of a curved member. To maintain the original span, a horizontal thrust reaction will be initiated by the action of the restraining supports. This axial restraint force acts in a similar manner as the axial pre-stressing force.

## LITERATURE REVIEW

Generally, all codes recommend the practice of providing an initial camber, to overcome excessive deflections due to vertical loads.

CEB-FIB Model Code [2] states that in order to balance the deflections, fully or in part, and to prevent the unwanted effects, adequate cambers are introduced in the form-work during construction.

ACI [1] and Iraqi Building Code [3] specify that the maximum permissible deflection may be exceeded if camber is provided so that the total deflection minus camber does not exceed the permissible limit.

An upward deflection is sometimes introduced to the member. This deflection is equal to the downward deflection caused by dead loads only, especially when the dead load represents the largest share of loads [4].

## SCOPE OF RESEARCH

An attempt is made, in this research, to study the deflection of straight and camber beams in actual portal frames [Footings + Columns + Beams]. The deflection was measured during months July and September of the year **2003** every two hours in a day [readings start at **8:00 a.m.** and finished at **10:00 p.m.**] for ten days.

An attempt is made to search for the peak period, i.e. the period which the deflection takes its peak value (maximum value)within a day. It is believed that it is possible to make use of this peak period in actual buildings [as an example, reducing the load (live load) during this period depending on the type and performance of each building (commercial, industrial, residential, . . .)]. Also, it may be possible to make use of this peak period for load test, i.e. to perform load test on buildings during this peak period in order to give the decision of the load test taking into account the worst situation of environment daily changes.

An attempt is also made, to study the effect of camber beams (whether it is interior or not). To ensure the accuracy, all dial gages have been calibrated at the central Institution for Measuring and Quality Control.

## EXPERIMENTAL WORK

Three model portal frames were prepared [for general information of the portal frames, see **Appendix (A)**] as follows:

1- Single span frame (with straight beam) [Frame (**A**)], shown in **Fig. (1)**.
2- Single span frame (with cambered beam) [Frame (**B**)], shown **Fig. (2)**.
3- Triple span frame (with cambered beam) [Frame (**C**)], shown **Fig. (3)**.

The upward camber is chosen to be 4.6 % upward curvature (gives best results [5]). Dead load was applied on beams after frames were about more than **100 days** age. The date of the dead load application is **12/5/2003**, and that of live load application is **20/6/2003**. Deflection readings for frames (**A** & **C**) were from **15/7/2003** to **24/7/2003**, and that for frames (**A** & **B**) were from **11/9/2003** to **20/9/2003**. These periods were chosen to study the effect of Baghdad climate of hot weather (frames **A** & **C**) and moderate weather (frames **A** & **B**).

Structural analysis indicates that the total ultimate load is (**5.383 kN/m**). According to load test requirements, **85%** of the total load should be considered as total test load, hence:

**Total Test Load = 0.85 (5.383) = 4.576 kN/m**

**Beam self weight = 0.072 kN/m**

**Super imposed dead load = 2.461 kN/m (assumed**, to use equal concrete block rows, each row contain equal number of concrete blocks)

**Total dead load = 2.533 kN/m**

**Hence test live load = 4.576 – 2.533 = 2.043 kN/m**

Dead and live loads were applied (experimentally) using concrete blocks and sags filled with gravel and hanged on steel pipes. The loads were applied at the same time for all frames.

**Tables (1)**, **(2)**, **(3)** and **(4)** give the measured deflection of the portal frames during fourteen hours of ten days of the research.

**Fig. (1)** shows the relationship between the average measured deflection and daily hours for frames (**A** & **C**), whereas **Fig. (2)** shows the same relationship for frames (**A** & **B**). **Fig. (3)** shows the same relationship for frame (**A**) at both months (**July and September**).

To ensure that there is no settlement in the foundation, the soil is compacted, then a brick layer is placed under a thin concrete blinding layer on which experimental models were cast.

For theoretical verification of the deflection results obtained experimentally, the following formulas were applied [1,6]:

$$\Delta_{2i} = \frac{5L^2}{48E_c I_e}[M_2 - \tfrac{1}{10}(M_1 + M_3)] \quad \text{.......(1)}$$

and

$$\Delta_{(cp+sh)} = \lambda.(\Delta_i)_{sust} \quad \text{.......(2)}$$

$$\lambda = \frac{\xi}{1 + 50\rho`} \quad \text{.......(3)}$$

where

$E_c$ is the modulus of elasticity.

$I_e$ is the effective moment of inertia.

$M_1$ & $M_3$ are the moments at the left and right ends respectively.

$M_2$ is the moment at mid-span of the beam.

$\lambda$ & $\xi$ are the long term deflection multiplier and coefficient respectively.

$(\Delta_i)_{sust}$ is the immediate deflection due to sustained load.

$\Delta_{(cp+sh)}$ is the long term deflection due to creep and shrinkage.

$\Delta_{2i}$ is the immediate deflection.

Total (immediate plus long term) theoretical deflections are given at the bottom of Tables (1, 2, 3 & 4), which indicate that the experimental results are acceptable.

It can be seen from **Tables (1)**, **(2)**, **(3)** and **(4)** and **Figs. (4)**, **(5)** and **(6)**, the following remarks:

1- Straight beam (Frame **A**) reaches peak value (maximum deflection) within a day faster than camber beams (Frames **B** & **C**).

2- Straight beam (Frame **A**) is able to rebound the deflection starting from the time of the peak value up to **8:00 a. m.** of the following day, while the cambered beam is able to rebound the deflection starting from the time of the peak value up to about **11:00 a. m.** (as an average). This situation makes the cambered beam capable to withstand the action of sustained load and environment more than the straight beam.

3- The ability of a cambered beam to rebound the deflection is better than that of straight beam. Hence, it is possible to suggest increasing the service life time in the design codes for buildings with camber members (beams and slabs) more than service life time of buildings with straight members only.

4- Straight beam suffers from temperature difference (Morning, Noon, Evening) more than camber beam.

5- Frame (**A**) reaches peak value of deflection at **6:00 p.m.** in **July**, and at **4:00 p. m.** in **September**. This means that due to the environment changes and due to sustained load, the straight beam will suffer from the reduction of its ability to withstand the external action (effect) done on it.

6- From **Tables (1)**, **(2)**, **(3)** and **(4)**, it can be seen that the range of daily hours for peak values of deflection is as follows:

**4:00** to **8:00 p.m.**] for frame (**A**) in **July** and **September**.
[**6:00** to **8:00 p.m.**] for frame (**B**) in **September**.
[**8:00** to **10:00 p.m.**] for frame (**C**) in **July**.

7- It is possible to conclude that the cambered beam (Frames **B** & **C**) is better than straight beam (Frame **A**).

8- It is possible to conclude that the camber beam will be better if it is interior beam (Frame **C**) compared to single span beam (Frame **B**).

## CONCLUSIONS

1- It is preferable to perform load test on straight members during the period [**4:00 p.m. – 8:00 p.m.**], and for cambered members during the period [**6:00 p.m. – 10:00 p.m.**] in order to give load test decision taking into account the worst case of daily deflection changes (peak value).

2- It is preferable for a straight beam to be cambered one to improve the beam behavior.

## REFERENCES

**[1]** "Building Code Requirements For Structural Concrete", ACI 318M-2002, and Commentary – ACI 318MR-2002, American Institute, Detroit, Michigan.

**[2]** CEB-FIB Model Code for Concrete Structures, 3rd Edition, 1978.

**[3]** "Iraqi Building Code Requirements for Reinforced Concrete", Code 1/ 1987, Building Research Center, Scientific Research Council.

**[4]** Salvadori and Heller, "Structure in Architecture ", Prentice - Hall, Inc., Englewood Cliffs, New Jersey.

**[5]** Shasha, Kais A. O., " Control of Camber of Concrete Beams to Minimize Steel Reinforcement ", M. Sc. Thesis, University of Baghdad, 1990.

**[6] الدكتور هاني محمد فهمي ، "تصاميم الخرسانة المسلحة"، مركز التعريب والنشر، الجامعة التكنولوجية، بغداد، 1986.**

**Table (1) Deflection around day for frame (A) (mm) [during July 2003].**

| Day | Hour | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **8:00** | **10:00** | **12:00** | **2:00** | **4:00** | **6:00** | **8:00** | **10:00** |
| **15/7** | 3.291 | 3.311 | 3.313 | 3.331 | 3.375 | 3.376 | 3.380 | 3.378 |
| **16/7** | 3.286 | 3.295 | 3.313 | 3.331 | 3.376 | 3.376 | 3.376 | 3.358 |
| **17/7** | 3.287 | 3.304 | 3.322 | 3.347 | 3.394 | 3.392 | 3.395 | 3.395 |
| **18/7** | 3.295 | 3.331 | 3.349 | 3.362 | 3.404 | 3.401 | 3.385 | 3.369 |
| **19/7** | 3.318 | 3.349 | 3.368 | 3.388 | 3.412 | 3.422 | 3.412 | 3.398 |
| **20/7** | 3.322 | 3.349 | 3.369 | 3.393 | 3.421 | 3.430 | 3.428 | 3.412 |
| **21/7** | 3.349 | 3.371 | 3.383 | 3.396 | 3.438 | 3.443 | 3.434 | 3.421 |
| **22/7** | 3.351 | 3.369 | 3.371 | 3.386 | 3.434 | 3.440 | 3.434 | 3.434 |
| **23/7** | 3.358 | 3.377 | 3.380 | 3.403 | 3.447 | 3.439 | 3.443 | 3.443 |
| **24/7** | 3.347 | 3.359 | 3.368 | 3.394 | 3.430 | 3.434 | 3.435 | 3.435 |
| **Aver-age** | **3.320** | **3.342** | **3.354** | **3.373** | **3.413** | **3.415** | **3.412** | **3.404** |
| **Final average deflection = 3.379 mm** | | | | | | | | |
| **Theoretical average deflection = 5.479 mm** | | | | | | | | |

**Table (2) Deflection around day for frame (C) (mm) [during July 2003].**

| Day | Hour | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **8:00** | **10:00** | **12:00** | **2:00** | **4:00** | **6:00** | **8:00** | **10:00** |
| **15/7** | 2.111 | 2.099 | 2.091 | 2.095 | 2.101 | 2.132 | 2.137 | 2.137 |
| **16/7** | 2.108 | 2.100 | 2.095 | 2.090 | 2.110 | 2.130 | 2.146 | 2.145 |
| **17/7** | 2.110 | 2.095 | 2.090 | 2.100 | 2.115 | 2.150 | 2.158 | 2.157 |
| **18/7** | 2.103 | 2.100 | 2.098 | 2.105 | 2.115 | 2.140 | 2.152 | 2.150 |
| **19/7** | 2.117 | 2.112 | 2.108 | 2.110 | 2.120 | 2.126 | 2.150 | 2.150 |
| **20/7** | 2.118 | 2.110 | 2.105 | 2.121 | 2.133 | 2.152 | 2.155 | 2.158 |
| **21/7** | 2.140 | 2.130 | 2.125 | 2.118 | 2.139 | 2.152 | 2.160 | 2.160 |
| **22/7** | 2.143 | 2.140 | 2.130 | 2.133 | 2.135 | 2.160 | 2.165 | 2.163 |
| **23/7** | 2.148 | 2.144 | 2.141 | 2.143 | 2.150 | 2.164 | 2.170 | 2.170 |
| **24/7** | 2.151 | 2.130 | 2.115 | 2.120 | 2.140 | 2.160 | 2.163 | 2.162 |
| **Aver-age** | **2.125** | **2.116** | **2.110** | **2.114** | **2.126** | **2.147** | **2.156** | **2.155** |
| **Final average deflection = 2.131 mm** | | | | | | | | |
| **Theoretical average deflection = 3.468 mm** | | | | | | | | |

**Table (3) Deflection around day for frame (A) (mm) [during September 2003].**

| Day | Hour | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **8:00** | **10:00** | **12:00** | **2:00** | **4:00** | **6:00** | **8:00** | **10:00** |
| **11/9** | 4.135 | 4.155 | 4.152 | 4.252 | 4.358 | 4.365 | 4.358 | 4.358 |
| **12/9** | 4.138 | 4.154 | 4.155 | 4.251 | 4.357 | 4.402 | 4.357 | 4.357 |
| **13/9** | 4.140 | 4.163 | 4.161 | 4.258 | 4.365 | 4.365 | 4.365 | 4.365 |
| **14/9** | 4.143 | 4.177 | 4.180 | 4.280 | 4.396 | 4.384 | 4.390 | 4.385 |
| **15/9** | 4.146 | 4.179 | 4.182 | 4.279 | 4.391 | 4.382 | 4.389 | 4.379 |
| **16/9** | 4.148 | 4.190 | 4.189 | 4.286 | 4.398 | 4.387 | 4.393 | 4.392 |
| **17/9** | 4.151 | 4.199 | 4.204 | 4.299 | 4.413 | 4.397 | 4.410 | 4.407 |
| **18/9** | 4.155 | 4.210 | 4.206 | 4.306 | 4.410 | 4.396 | 4.410 | 4.407 |
| **19/9** | 4.158 | 4.217 | 4.221 | 4.318 | 4.427 | 4.406 | 4.423 | 4.421 |
| **20/9** | 4.161 | 4.227 | 4.232 | 4.328 | 4.437 | 4.414 | 437 | 4.433 |
| **Aver-age** | **4.148** | **4.187** | **4.188** | **4.286** | **4.395** | **4.390** | **4.393** | **4.390** |
| **Final average deflection = 4.297 mm** | | | | | | | | |
| **Theoretical average deflection = 6.324 mm** | | | | | | | | |

**Table (4) Deflection around day for frame (B) (mm) [during September 2003].**

| Day | Hour | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **8:00** | **10:00** | **12:00** | **2:00** | **4:00** | **6:00** | **8:00** | **10:00** |
| **11/9** | 3.606 | 3.585 | 3.604 | 3.638 | 3.726 | 3.766 | 3.760 | 3.663 |
| **12/9** | 3.595 | 3.579 | 3.598 | 3.634 | 3.721 | 3.762 | 3.705 | 3.636 |
| **13/9** | 3.600 | 3.573 | 3.585 | 3.602 | 3.623 | 3.764 | 3.634 | 3.609 |
| **14/9** | 3.600 | 3.529 | 3.560 | 3.595 | 3.616 | 3.767 | 3.641 | 3.624 |
| **15/9** | 3.605 | 3.560 | 3.594 | 3.622 | 3.673 | 3.770 | 3.723 | 3.662 |
| **16/9** | 3.610 | 3.564 | 3.583 | 3.609 | 3.684 | 3.768 | 3.673 | 3.624 |
| **17/9** | 3.611 | 3.534 | 3.561 | 3.584 | 3.637 | 3.762 | 3.672 | 3.623 |
| **18/9** | 3.611 | 3.535 | 3.553 | 3.573 | 3.586 | 3.760 | 3.602 | 3.573 |
| **19/9** | 3.598 | 3.515 | 3.547 | 3.558 | 3.579 | 3.765 | 3.596 | 3.579 |
| **20/9** | 3.599 | 3.496 | 3.536 | 3.562 | 3.578 | 3.780 | 3.597 | 3.585 |
| **Aver-age** | **3.604** | **3.547** | **3.572** | **3.598** | **3.642** | **3.766** | **3.660** | **3.618** |
| **Final average deflection = 3.626 mm** | | | | | | | | |
| **Theoretical average deflection = 5.602 mm** | | | | | | | | |

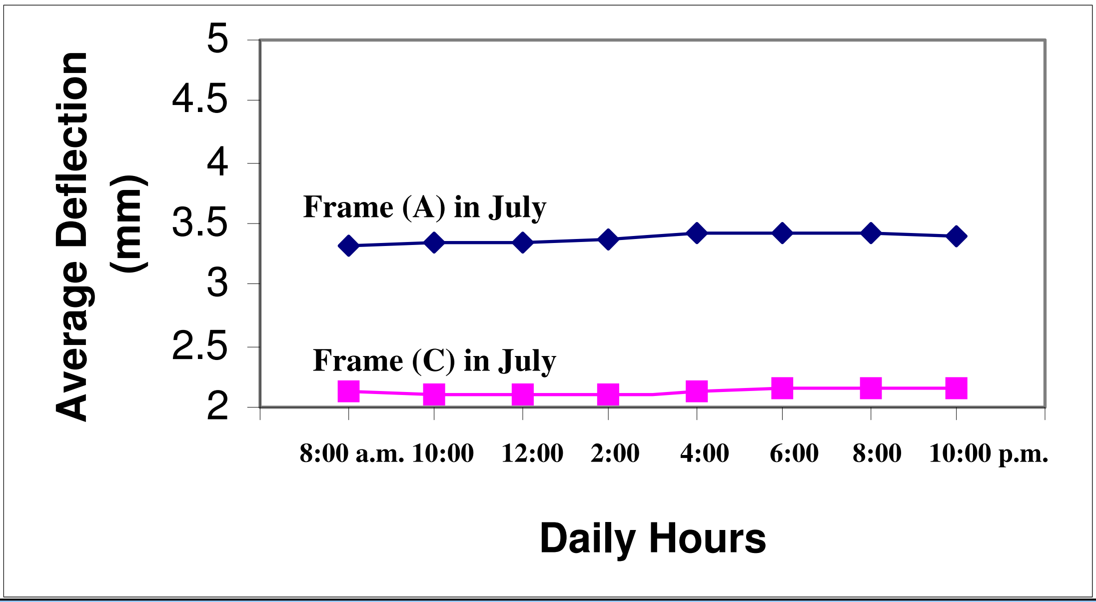



**Fig. (4) Deflection – Hour relationship for frames (A & C).**

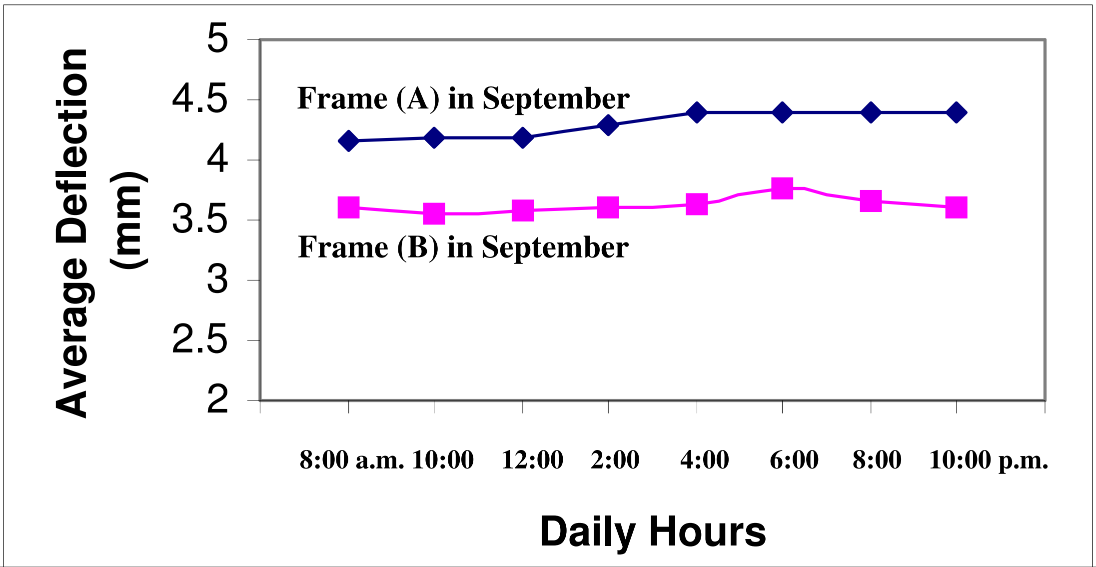



**Fig. (5) Deflection – Hour relationship for frames (A & B).**

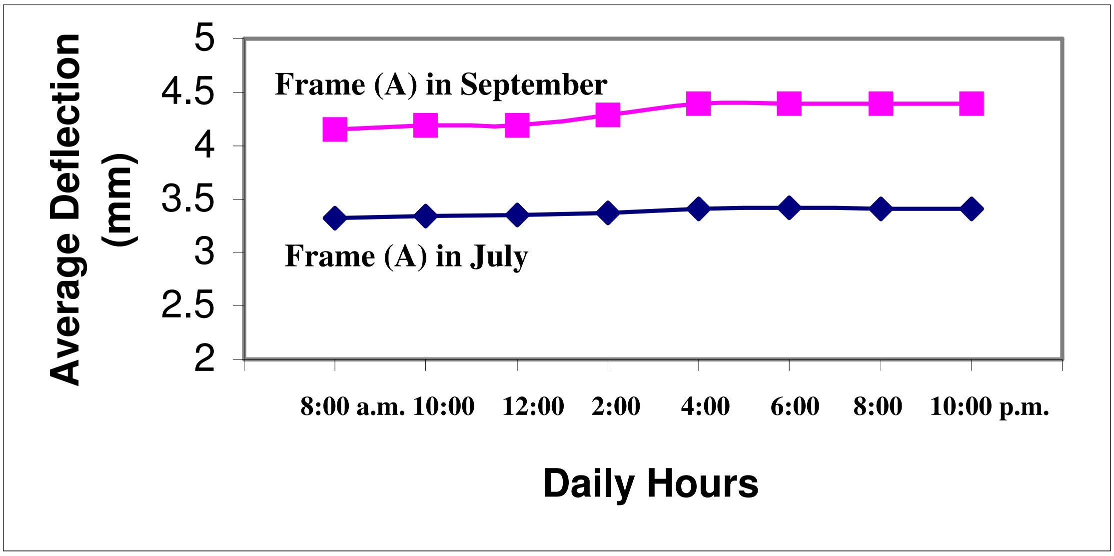
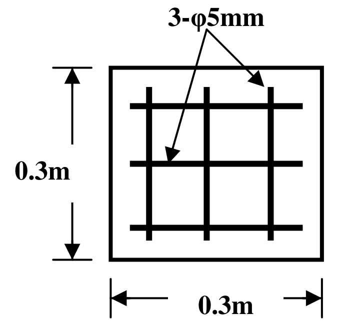
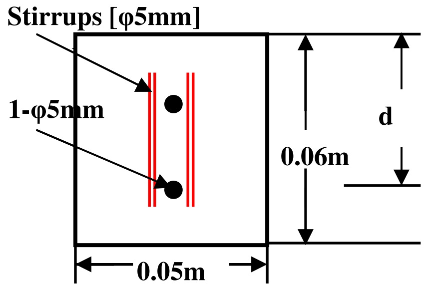



**Fig. (5) Deflection – Hour relationship for frames (A & B).**

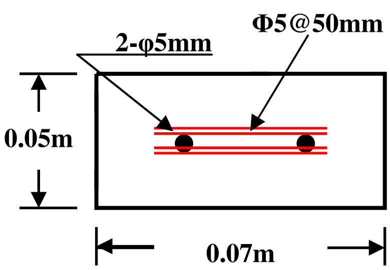
## APPENDIX (A)




[A] Footing of all portal frames (thickness=0.1m)




(B) Beam section for portal frames [d is variable].




(C) Column section for all portal frames

**STIRRUP DISTRIBUTION**

| | |
|---|---|
| 1st stirrup @ 0.11m<br>2nd stirrup @ 0.26m<br>3rd stirrup @ 0.41m | From face of support |

**General Information:**
**For all portal beams :**
**$f'_c$ = 26.59 MPa (Concrete).**
**$f_y$ = 774 MPa (Steel Reinforcement).**
**Degree Of curvature ($C_r$) = 4.6 %**
**Portland Cement (Type I).**