Chapter Four

# Results and Discussion of Results

## 4.1 Forwarding

- **Behavior and Strength of columns**

The failure of the tied column is usually initiated by the spalling *(falling)* of the concrete cover followed by the buckling of the longitudinal bars due to the lack of the lateral support provided by the cover. The failure of axially loaded reinforced concrete columns is brittle with little or no warning. Up to approximately 80% of the total load, no sign of cracking appears. Suddenly vertical cracks start to appear with concrete cover failure leading to the collapse of the column [17].

Since failure of columns is often sudden with a high potential for loss of life, columns are designed with a much higher safety factor than beams. Because perfect straight columns subjected to pure axial loading are subjected to the brittle failure mode, the Egyptian code increases the strength reduction factors for concrete and steel to 1. 75 and 1.34, respectively [17].

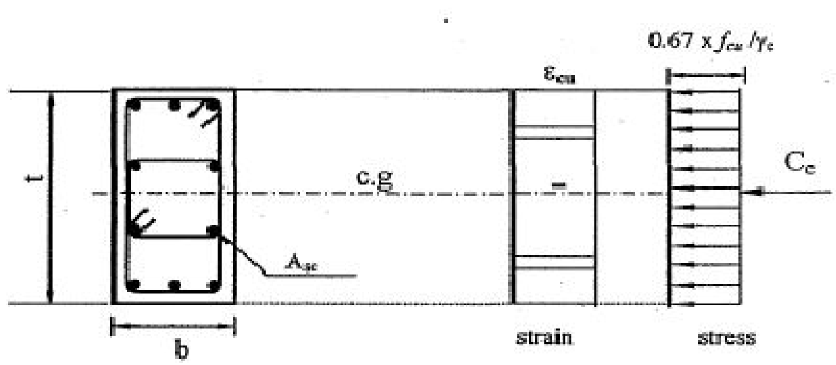


*Fig. [4.1]: Strain and stress distributions for columns under axial loads.*

When a column is subjected to axial loads, longitudinal strain develops in both concrete and steel. Because of the perfect bond between steel and concrete, the strains in the concrete and steel are equal. The total carrying capacity of the column is the summation of concrete and steel contributions. At failure, all the steel reinforcement is assumed 'to reach yielding. Applying the equilibrium equation for the section shown in Fig. (4.1) above;

$$P_u = \frac{0.67 fcu\ b\ t}{\Upsilon c} + \frac{Asc \times fy}{\Upsilon s} \quad \ldots \qquad \ldots.. \ (4.1)$$

$$P_u = \frac{0.67 fcu\, b\, t}{1.75} + \frac{Asc \times fy}{1.34} =$$

$$0.38\, f_{cu}\, A_c + 0.75\, A_{sc}\, f_y \qquad \ldots\ldots\ldots \ (4.2)$$

*Where;*

$f_{cu}$ ≡ *The compression strength of concrete ,*

$fy$ ≡ *The characteristic strength of steel,*

$Ac$ ≡ *is the area of the concrete (b×t), and*

$Asc$ ≡ *is the total area of the steel reinforcement.*

The previous behavior is applied for perfect straight column , which are practically almost do not exist, Even for concentrically loaded column, most codes impose a minimum eccentricity to be considered in column design to account for dimensional inaccuracies and uncertainties in the line of axial loads. The ECP-203 minimum eccentricity is given by Eq. (4.3) as follows:

$$e_{min} = \text{bigger of} \begin{cases} 0.05t \\ 20\ mm \end{cases} \qquad \ldots\ldots\ldots\ldots.. \qquad (4.3)$$

The existence of moments leads to a reduction in axial load capacity. Thus code imposes a further reduction on column strength by reducing the capacity by about 10% giving the following equation.

$$P_u = 0.35\, fcu\, A_c + 0.67\, f_y\, A_{sc} \qquad \text{(4.4)}$$

## 4.2 Design results for load cases

The design of the case studied is carried out by using (Prokon) program as illustrated Tables (4.1), (4.2), (4.3), and (4.10), and Figures (4.2), (4.3) and (4.7).

***Table (4.1):*** *Design results for load cases with no ductility change.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | $M_X$ top (KN.m) | $M_X$ Bottom (KN.m) | $M_Y$ Top (KN.m) | $M_Y$ Bottom (KN.m) | Design load (KN) | Remark | $p_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 2% | 1960 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1588 |
| 4% | 1936 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1581 |
| 6% | 1887 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1566 |
| 8% | 1839 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1551 |
| 10% | 1815 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1544 |
| 12% | 1767 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1529 |
| 14% | 1720 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1514 |
| 16% | 1697 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1507 |
| 18% | 1651 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not Ok | 1493 |

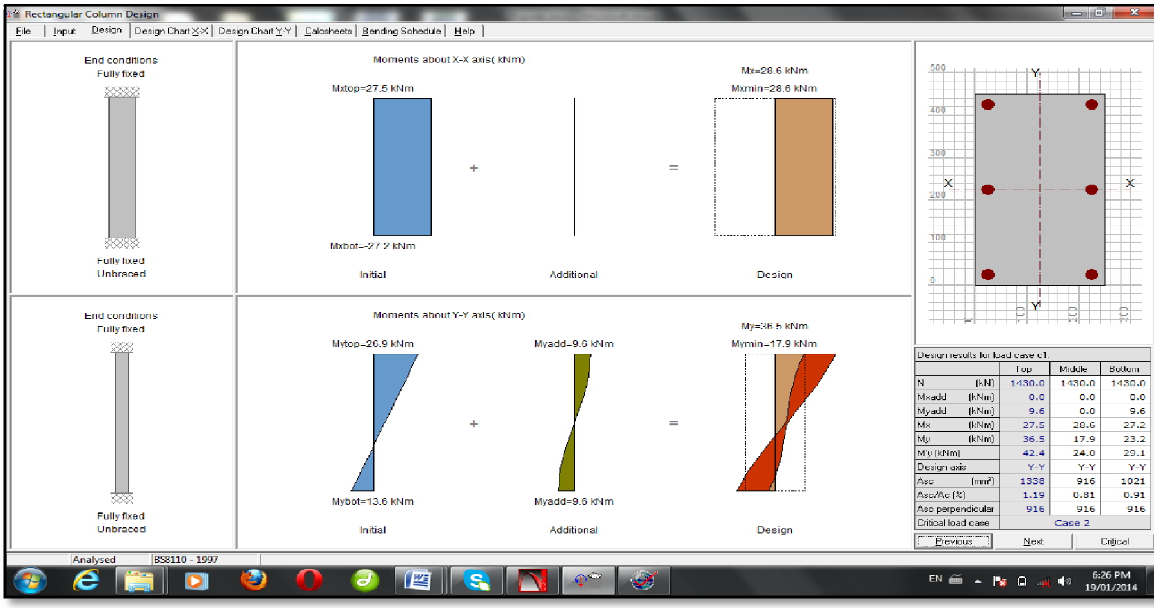


Fig. [4.2]: Design Moments for Control column and Other Columns.

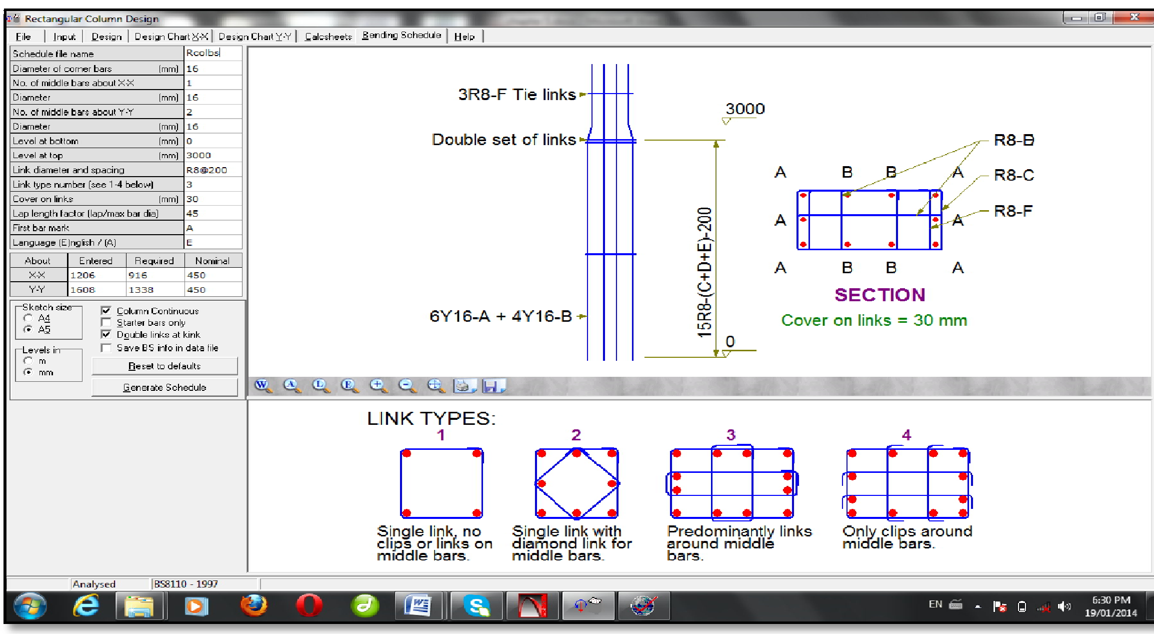


Fig. [4.3]: Bending Schedule for Control column with no ductility change.

***Table (4.2)**: Design results for Corrosion rate 2% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | $M_X$ top (KN.m) | $M_X$ Bottom (KN.m) | $M_Y$ Top (KN.m) | $M_Y$ Bottom (KN.m) | Design load (KN) | Remark | $P_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 2% | 1960 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1575 |
| 2% | 1960 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1562 |
| 2% | 1960 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1549 |
| 2% | 1960 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1536 |
| 2% | 1960 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1523 |
| 2% | 1960 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1510 |
| 2% | 1960 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |

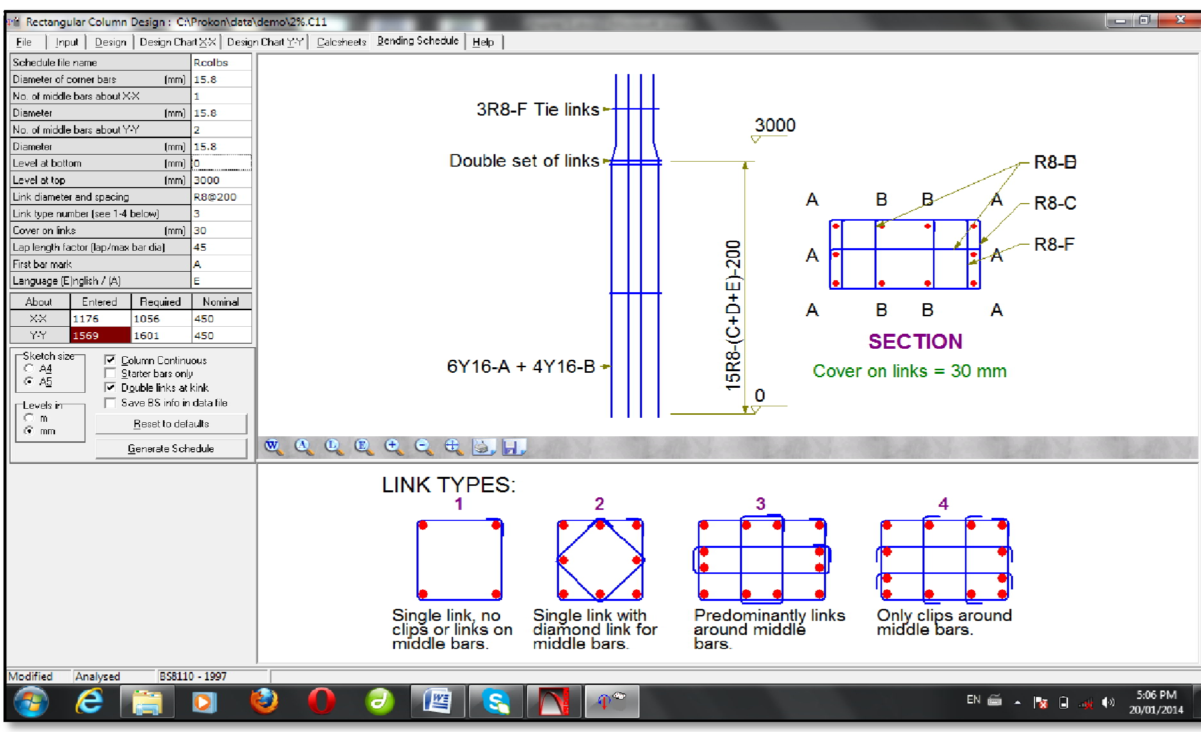


Fig. [4.4]: Bending Schedule for 2% reduction in steel area & 14% reduction in ductility [$f_y$ = 390 Mpa].

***Table (4.3)***: *Design results for Corrosion rate 4% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | $M_X$ top (KN.m) | $M_X$ Bottom (KN.m) | $M_Y$ Top (KN.m) | $M_Y$ Bottom (KN.m) | Design load (KN) | Remark | $P_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 4% | 1936 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1568 |
| 4% | 1936 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1555 |
| 4% | 1936 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1542 |
| 4% | 1936 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1529 |
| 4% | 1936 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1516 |
| 4% | 1936 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 4% | 1936 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |

***Table (4.4):*** *Design results for Corrosion rate 6% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | $M_X$ top (KN.m) | $M_X$ Bottom (KN.m) | $M_Y$ Top (KN.m) | $M_Y$ Bottom (KN.m) | Design load (KN) | Remark | $P_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 6% | 1887 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1553 |
| 6% | 1887 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1540 |
| 6% | 1887 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1528 |
| 6% | 1887 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1515 |
| 6% | 1887 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 6% | 1887 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 6% | 1887 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |

***Table (4.5)**: Design results for Corrosion rate 8% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | $M_X$ top (KN.m) | $M_X$ Bottom (KN.m) | $M_Y$ Top (KN.m) | $M_Y$ Bottom (KN.m) | Design load (KN) | Remark | $P_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 8% | 1839 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1539 |
| 8% | 1839 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1526 |
| 8% | 1839 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1514 |
| 8% | 1839 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 8% | 1839 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 8% | 1839 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 8% | 1839 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |

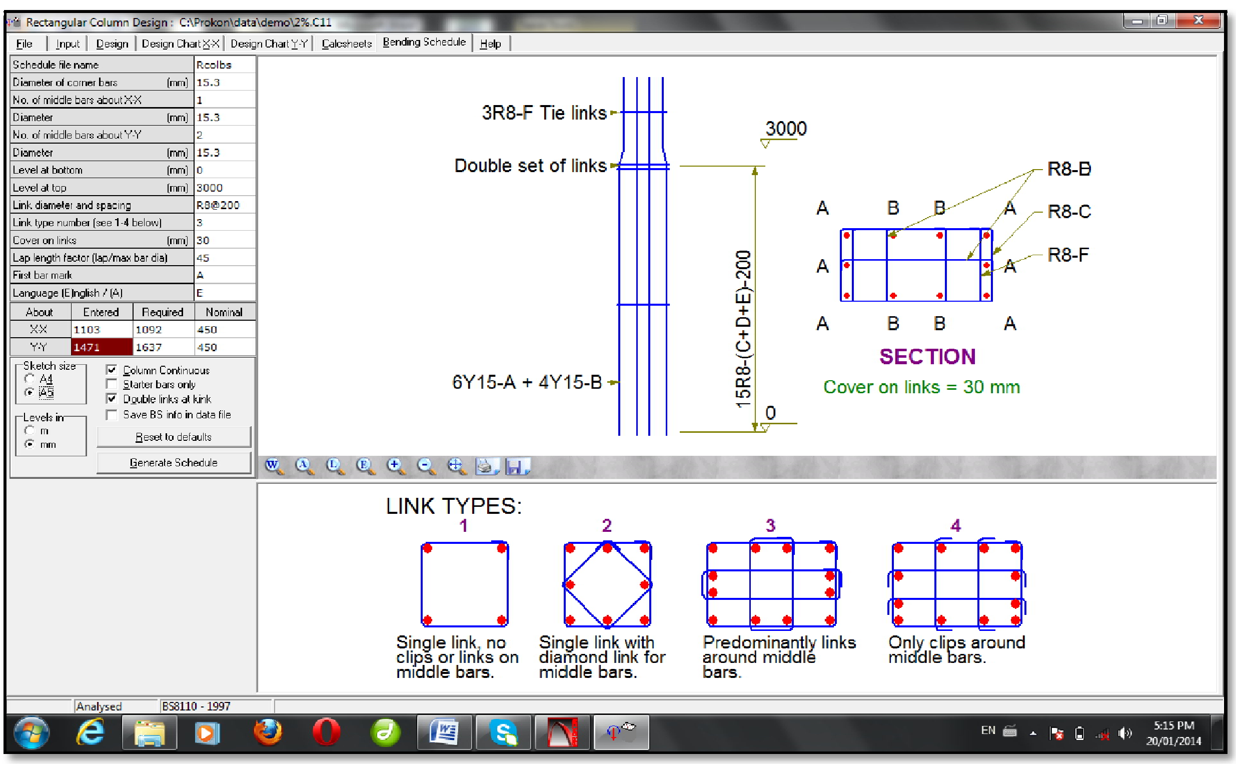


Fig. [4.5]: Bending Schedule for 8% reduction in area & 8% reduction in ductility. [$f_y$ = 420 Mpa].

***Table (4.6):*** *Design results for Corrosion rate 10% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | $M_x$ top (KN.m) | $M_x$ Bottom (KN.m) | $M_y$ Top (KN.m) | $M_y$ Bottom (KN.m) | Design load (KN) | Remark | $p_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 10% | 1815 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1535 |
| 10% | 1815 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1519 |
| 10% | 1815 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1507 |
| 10% | 1815 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 10% | 1815 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 10% | 1815 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 10% | 1815 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |

***Table (4.7)****: Design results for Corrosion rate 12% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | $M_X$ top (KN.m) | $M_X$ Bottom (KN.m) | $M_Y$ Top (KN.m) | $M_Y$ Bottom (KN.m) | Design load (KN) | Remark | $P_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 12% | 1767 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Ok | 1517 |
| 12% | 1767 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1505 |
| 12% | 1767 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 12% | 1767 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 12% | 1767 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 12% | 1767 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 12% | 1767 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |

***Table (4.8):*** *Design results for Corrosion rate 14% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | $M_X$ top (KN.m) | $M_X$ Bottom (KN.m) | $M_Y$ Top (KN.m) | $M_Y$ Bottom (KN.m) | Design load (KN) | Remark | $P_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 14% | 1720 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1503 |
| 14% | 1720 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 14% | 1720 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 14% | 1720 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 14% | 1720 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 14% | 1720 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 14% | 1720 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |

***Table (4.9)***: *Design results for Corrosion rate 16% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | MX top (KN.m) | MX Bottom (KN.m) | MY Top (KN.m) | MY Bottom (KN.m) | Design load (KN) | Remark | $p_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 16% | 1697 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Limited | 1507 |
| 16% | 1697 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 16% | 1697 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 16% | 1697 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 16% | 1697 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 16% | 1697 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 16% | 1697 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |
| 16% | 1697 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | - |

***Table (4.10)**: Design results for* Corrosion rate *18% with change in ductility.*

| Corrosion rate | $A_{sc}$ ($mm^2$) | Ductility reduction | $M_X$ top (KN.m) | $M_X$ Bottom (KN.m) | $M_Y$ Top (KN.m) | $M_Y$ Bottom (KN.m) | Design load (KN) | Remark | $P_u$ (KN ) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Control | 1604 |
| 18% | 2010 | 460 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | |
| 18% | 1651 | 450 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | |
| 18% | 1651 | 440 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | |
| 18% | 1651 | 430 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | |
| 18% | 1651 | 420 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | |
| 18% | 1651 | 410 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | |
| 18% | 1651 | 400 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | |
| 18% | 1651 | 390 | 27.2 | 26.9 | -27.5 | 13.6 | 1430 | Not ok | |

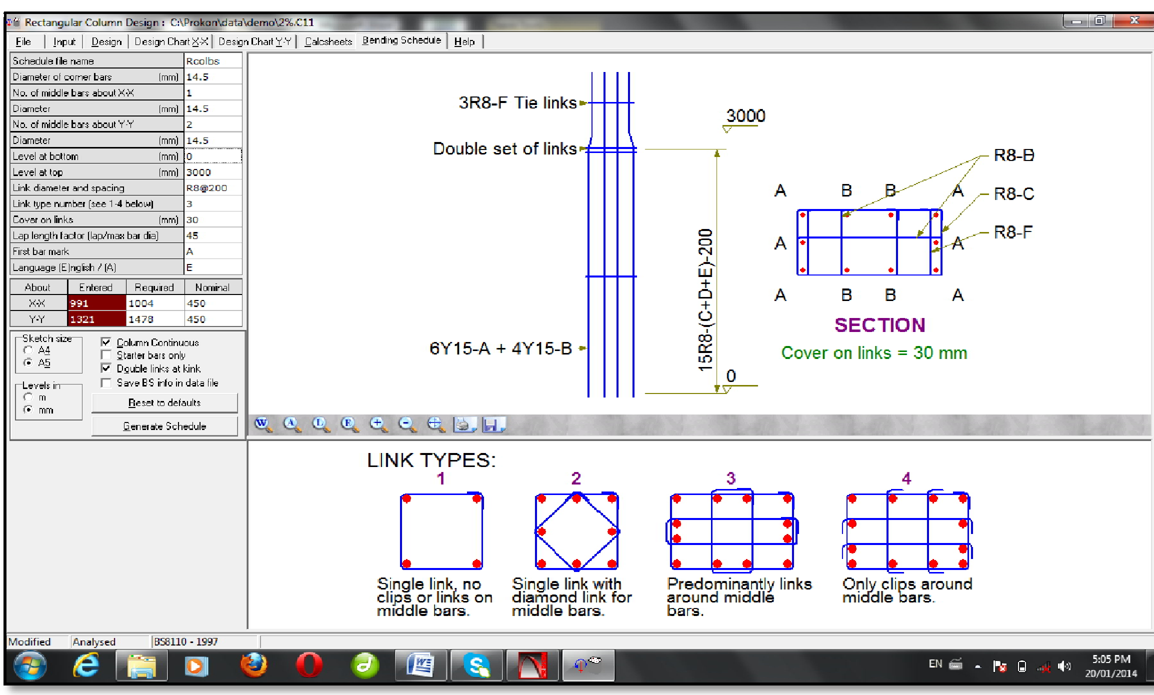


Fig. [4.6]: Bending Schedule for 18% reduction in area & 8% reduction in ductility [$f_y$ = 420 Mpa].

## 4.3 Discussion

The selected building was analyzed and designed using the structural programs Etabs and Prokon.

The results of analysis were extracted in the form of diagrams showed the bending moments and axial force which were the worst value.

From results obtained in Table (4.1), the Design results for load cases with no ductility change. The ultimate load carrying capacity is decreased with the increasing of the corrosion rate (0% form to 18%). At a corrosion equal to ratio 16% ultimate limited load result is equal to 1507 KN but the structure is not safe in a corrosion ratio equal to 18%.

From results obtained in Table (4.2), the Design results for Corrosion rate 2% with change in ductility. The ultimate load carrying capacity of the column is decreased by decreasing the steel ductility, and the ultimate Limited load result is equal to 1510 KN for 400 $KN/mm^2$ ductility and equal 1523 KN for 410 $KN/mm^2$ ductility.

From results obtained in Table (4.3), the Design results for Corrosion rate 4% with change in ductility. The ultimate load carrying capacity of the column is decreased by decreasing the steel ductility, and the ultimate Limited load result is equal to 1516 KN for 410 $KN/mm^2$ ductility and equal 1529 KN for 420 $KN/mm^2$ ductility.

From results obtained in Table (4.4), the Design results for Corrosion rate 6% with change in ductility. The ultimate load carrying capacity of the column is decreased by decreasing the steel ductility, and the ultimate

Limited load result is equal to 1515 KN for 420 $KN/mm^2$ ductility and equal 1528 KN for 430 $KN/mm^2$ ductility.

From results obtained in Table (4.5), the Design results for Corrosion rate 8% with change in ductility. The ultimate load carrying capacity of the column is decreased by decreasing the steel ductility, and the ultimate Limited load result is equal to 1514 KN for 430 $KN/mm^2$ ductility and equal 1526 KN for 440 $KN/mm^2$ ductility.

From results obtained in Table (4.6), the Design results for Corrosion rate 10% with change in ductility. The ultimate load carrying capacity of the column is decreased by decreasing the steel ductility, and the ultimate Limited load result is equal to 1507 KN for 430 $KN/mm^2$ ductility and equal 1519 KN for 440 $KN/mm^2$ ductility.

From results obtained in Table (4.7), the Design results for Corrosion rate 12% with change in ductility. The ultimate load carrying capacity of the column is decreased by decreasing the steel ductility, and the ultimate Limited load result is equal to 1505 KN for 440 $KN/mm^2$ ductility and equal 1517 KN for 450 $KN/mm^2$ ductility.

From results obtained in Table (4.9), the Design results for Corrosion rate 16% with change in ductility. The ultimate load carrying capacity of the column is decreased by decreasing the steel ductility, and the ultimate Limited load result is equal to 1507 KN for 460 $KN/mm^2$ ductility and the structure is not safe under increasing this ratio of corrosion or change of steel ductility.

- After commencement of corrosion the reinforcement will deteriorate, which is associated with reduction in area of the steel. The results show that only after corrosion has started the reliability of the column decreased slowly. With elapse of time corrosion penetration starts to affect the reliability of the column significantly.
- The Reduction in rebar ductility directly influences the stiffness of the structure, the possibility for force and moment redistribution, and limits the load-carrying capacity of structure, its quicken the deteriorate in structure.