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Analysis and Design of Different Types of Slabs using Various Codes

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Abstract Reinforced concrete slab is one of the most important structural elements of a building. There are different types of slabs such as one-way or two-way solid slab, flat plate, one-way or two-way ribbed slab etc. The economy and safety of building depends on choosing the right kind of slab and implementing the code requirements. In the absence of a national design code in Libya, any of the international codes such as ACI 318-11, BS 8110-97 or Eurocode 2 can be used to design slab. In this paper, a comparative study of different types of slabs is conducted to find the most suitable or optimal solution using different codes. For this purpose, the software "Autodesk Robot Structural Analysis" is used. Four parameters are considered for comparison and they are: deflection, concrete volume, weight of steel reinforcement used and cost. The software's special feature for quantity surveying is used to determine the concrete volume and weight of steel reinforcement. After design and comparison, it is found that ACI code requires more reinforcement and concrete, which leads to greater total price but it gives less deflection. On the other hand, BS code gives less total price but more deflection.

Keywords: ACI 318-11, BS 8110-97, Eurocode 2, RC Slab.

تحليل و تصميم أنواع مختلفة من البلاطات باستخدام كودات مختلفة

غصن الكفري[1] و *محمد شهنواز شركر[2] و محمد شائزالدين شركر[2]
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الملخص بلاطة الخرسانة المسلحة هي واحدة من أهم العناصر الانشائية للمبنى. هناك أنواع مختلفة من البلاطات مثل البلاطات المصمتة في إتجاه واحد أو إتجاهين، البلاطات اللاكمرية، البلاطات المعصبة في إتجاه واحد أو إتجاهين الخ. يعتمد اقتصاد وسلامة المبنى على اختيار النوع المناسب من البلاطات وتنفيذ متطلبات الكود. في ضل عدم وجود كود تصميم وطني في ليبيا، يمكن استخدام أي من الكودات الدولية مثل الكود الامريكي او الكود البريطاني او الكود الأوروبي لتصميم البلاطات. في هذه الورقة، تم إجراء دراسة مقارنة لأنواع مختلفة من البلاطات لإيجاد الحل الأنسب أو الأمثل باستخدام كودات مختلفة. ولهذا الغرض، تم استخدام البرنامج "أوتوديسك روبوت لتحليل الانشائي". أخذ في الاعتبار أربعة عوامل للمقارنة وهي: الترخيم، حجم الخرسانة، وزن حديد التسليح المستخدم والتكلفة. تم استخدام ميزة خاصة للبرنامج لحساب الكميات وتحديد حجم الخرسانة ووزن حديد التسليح. بعد التحليل والمقارنة وجد أن الكود الامريكي يتطلب المزيد من الحديد والخرسانة مما يؤدي إلى زيادة السعر الإجمالي لكنه يعطي أقل ترخيم. من ناحية أخرى، الكود البريطاني يعطي أقل سعر الإجمالي ولكن أكثر ترخيم.

الكلمات المفتاحية: الكود الأمريكي، الكود البريطاني، الكود الأوروبي و البلاطات الخرسانة المسلحة.

Introduction:

The structural design of most buildings worldwide is based on national or international codes of practice. These guide the engineer in the general appraisal of the overall structural scheme, detailed analysis and design. Codes of practice are basically guides drawn up by experienced engineers and a team of professionals, and they provide a framework for addressing issues of safety and serviceability in structural engineering design [6]. Although the main purpose of these design codes is to provide guidelines for the design of safe and economic structures; the principles, procedures and assumptions employed to achieve this may differ from one code to another. Studies have also shown that some codes are more economical than others [7]. In this study, three codes will be compared and they are ACI 318-11, BS 8110-97 and Eurocode 2. The objective of this research is to make a comparison among various codes for different types of slabs based on four factors: deflection, concrete volume, weight of steel reinforcement used and cost.

Project Description: The building structure selected for this study is a proposed multi-storey office building. It has an area of 480 m^2 with 24 m length and 20 m width. The building consists of two rows of office rooms and a corridor between them. The office rooms will further be divided into smaller cubicles with internal partitions. The spacing between columns are 4 meters and 8 meters as shown in Fig. 1 and the column sections are 300x300 mm^2. For the purpose of the

study, only one story is selected to focus on the behaviour of the slab-beam system. For this study, Robot Structural Analysis Software is used. The types of slabs considered are one-way solid slab, two-way solid slab, one-way ribbed slab and flat plate slab. Each type of slab system is analysed and designed based on three codes: ACI, BS and EC2.

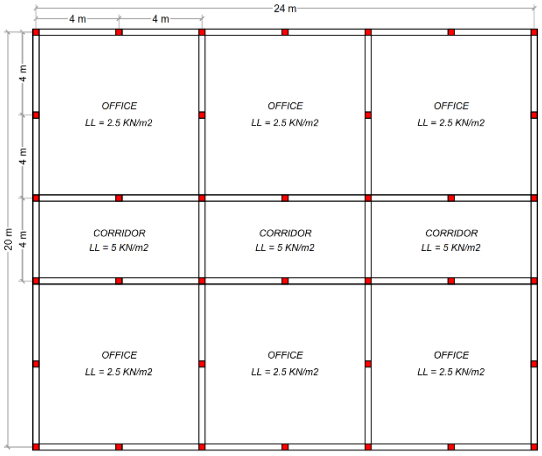

Fig. 1: Floor Plan and Column Distribution

Based on the materials used in the building, the dead load (DL) is calculated as 3.21 KN/m² and the live load (LL) is taken as 2.5 KN/m² on the office floors and 5 KN/m² on the corridor. The compressive strength of concrete, f_{cu} is taken as 30 MPa. The yield strength for main reinforcing bars, f_y is taken as 420 MPa and for the stirrups it is taken as f_{yv} = 300 MPa.

Methodology: At first computer modelling of each slab system (one-way, two-way, flat plate & one-way ribbed slab) was done. Boundary conditions (Bottom supports are fixed and upper supports are fixed but free in Z direction) were taken in order to represent the multiple story characteristics. Then the loads were applied. Figs. 2 to 5 show the modelling of these structures in the software.

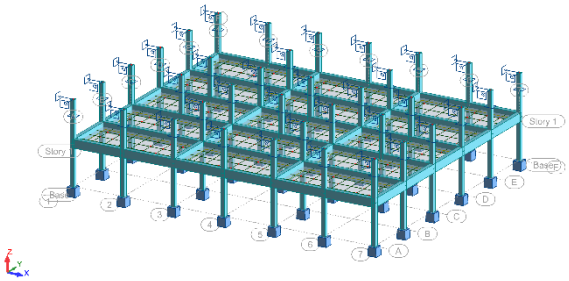

Fig. 2: One-Way Solid Slab after Modeling

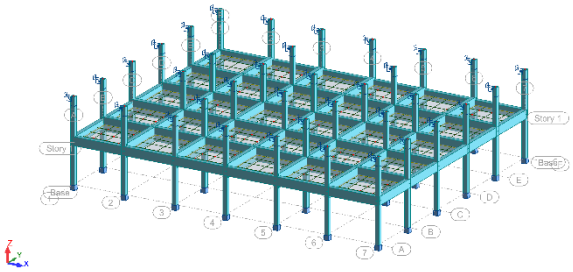

Fig. 3: Two-Way Solid Slab after Modeling

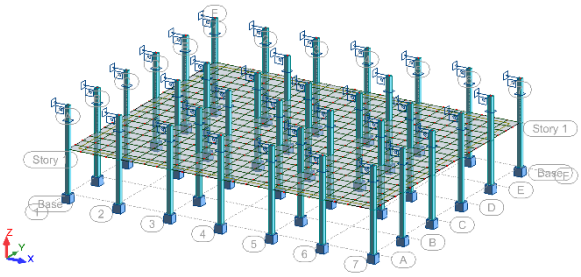

Fig. 4: Flat Plate Slab after Modeling

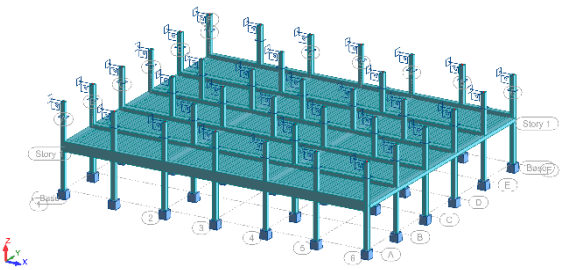

Fig. 5: One-Way Ribbed Slab after Modeling

Analysis & design of all the structural elements were carried out for each type of slab according to ACI 318-11 Metric, BS 8110-97 & Eurocode 2.

Quantity surveying for each type of slab was done by using the software. Some critical calculations were also done by hand. Fig. 6 shows concrete volume required and Fig. 7 is a part of the report given by the software which shows weight of steel reinforcement for one-way solid slab according to ACI. Similarly, quantity surveying is also done for other codes.

Type	Number	Length (m)	Unit weight (kG/m)	Bar weight (kG)	Total weight (kG)	Volume (m3)
C30_ACI						
B R30x65	2	20.00	477.23	9544.54	19089	7.80
B R30x65	2	24.00	477.23	11453.45	22907	9.36
B R30x75	2	20.00	550.65	11012.94	22026	9.00
B R30x75	4	24.00	550.65	13215.52	52862	21.60
C R30x30	72	3.20	220.26	704.83	50748	20.74
Total per sections						
B R30x65	4	88.00	477.23	41995.99	41996	17.16
B R30x75	6	136.00	550.65	74887.96	74888	30.60
C R30x30	72	230.40	220.26	50747.60	50748	20.74
Total					167632	68.50

Type	Number	Thickness (cm)	Unit weight (kG/m2)	Area (m2)	Volume (m3)	Total weight (kG)
C30_ACI						
TH16	15	16.0	391.57	480.00	76.80	187954
Total				480.00	76.80	187954

Fig. 6: Concrete Volume Required for One-Way Solid Slab

Material survey

- Concrete volume = 76.80 (m3)
- Formwork = 480.00 (m2)
- Slab circumference = 88.00 (m)
- Area of openings = 0.00 (m2)

- Steel Grade 420
- Total weight = 4794.13 (kG)
- Density = 62.42 (kG/m3)
- Average diameter = 10.0 (mm)
- Survey according to diameters:

Diameter	Length (m)	Weight (kG)
10	7768.25	4794.13

Fig. 7: Weight of Steel for One-Way Solid Slab

Cost of each slab system for different codes was done by using Microsoft Excel according to price in Libya. Then comparison of each slab system for different codes has been done on the basis of four factors. Finally conclusion is made for this study.

Results and Discussion: After performing the analysis, the obtained results were compared based on four factors. They are deflection of slab, concrete volume, weight of steel reinforcement and price of reinforced concrete. Table (1) shows the values of deflections for each type of slab according to different codes. From this table it can be seen that deflection in ACI is the least for all types of slabs except two-way solid slab. For the two-way solid slab it is found that the deflection is the least in EC2. On the other hand, deflection in BS is larger for all types of slabs compared to other codes. However all the deflection values for the three codes are very small and within the acceptable range.

Table (1) Comparison of Slabs Based on Deflection

Slab Type	Deflection in ACI (mm)	Deflection in BS (mm)	Deflection in EC2 (mm)
One-Way Solid Slab	5.60	10.70	6.90
Two-Way Solid Slab	6.50	14.10	4.40
Flat Plate	11.80	12.80	12.80
One-Way Ribbed Slab	2.40	7.50	5.00

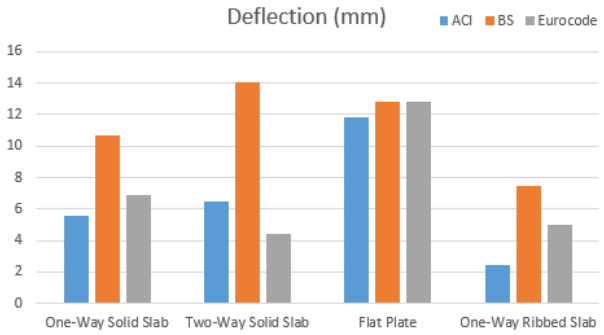

Fig. 8: Comparison of Slabs Based on Deflection

Table (2) shows the amount of concrete volume needed for construction of beams and slabs for each type of slab according to different codes. From this table and its graphical representation in Fig. 9 it is found that the quantity of concrete according to ACI is larger for all types of slabs. While for the BS it requires less amount of concrete for all types of slabs. On the other hand, the quantity of concrete required for EC2 is a little bit smaller than ACI. This explains the reason why deflection according to ACI is smaller and for BS is larger in Table (1). In the similar way, as the concrete volume for EC2 is near to ACI, the deflection of EC2 is also near to ACI.

Table (2) Comparison Based on Concrete Volume

ACI				
Slab Type	One-Way	Two-Way	Flat Plate	Ribbed Slab
Beams & Ribs (m^3)	47.76	75.96	-	74.72
Slabs (m^3)	76.80	52.80	129.60	33.60
Total (m^3)	124.56	128.76	129.60	108.32
BS				
Slab Type	One-Way	Two-Way	Flat Plate	Ribbed Slab
Beams & Ribs (m^3)	36.96	25.56	-	45.12
Slabs (m^3)	57.60	67.20	124.80	24.00
Total (m^3)	94.56	92.76	124.80	69.12
EC2				
Slab Type	One-Way	Two-Way	Flat Plate	Ribbed Slab
Beams & Ribs (m^3)	33.72	44.52	-	69.66
Slabs (m^3)	81.60	81.60	124.80	24.00
Total (m^3)	115.32	126.12	124.80	93.66

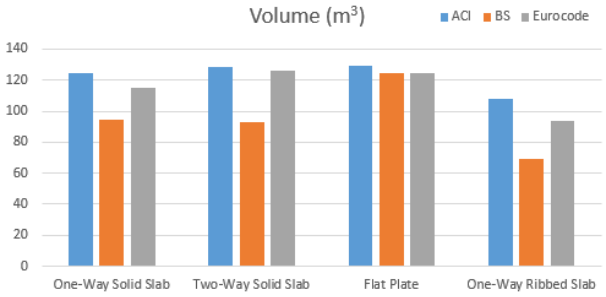

Fig. 9: Comparison Based on Concrete Volume

Table (3) shows the amount of steel reinforcement needed for beams and slabs for each type of slab according to different codes. From this table and its graphical representation in Fig. 10 it can be seen that, the weight of steel reinforcement is the least in BS code for all types of slabs except one-way solid slab. On the other hand, the weight of steel reinforcement in EC2 is the largest for all types of slabs except two-way solid slab.

Table (3) Comparison Based on Weight of Steel

ACI				
Slab Type	One-Way	Two-Way	Flat Plate	Ribbed Slab
Beams & Ribs (kg)	3757.00	7131.01	-	8717.07
Slabs (kg)	4794.13	8885.21	9298.98	1331.73
Total (kg)	8551.13	16016.5	9298.98	10048.80
BS				
Slab Type	One-Way	Two-Way	Flat Plate	Ribbed Slab
Beams & Ribs (kg)	3043.81	4553.89	-	7978.06
Slabs (kg)	6851.14	5320.82	8894.63	1331.73
Total (kg)	9894.95	9874.71	8894.63	9309.79
EC2				
Slab Type	One-Way	Two-Way	Flat Plate	Ribbed Slab
Beams & Ribs (kg)	3068.34	3617.05	-	8714.57
Slabs (kg)	7775.14	7461.55	10034.62	1331.73
Total (kg)	10843.48	11078.6	10034.62	10046.30

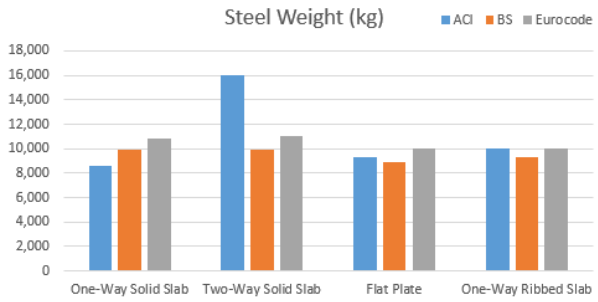

Fig. 10: Comparison Based on Steel

From the above results, it is found that based on deflection ACI code is the best. But based on volume of concrete and amount of steel reinforcement BS code is the best. The last parameter in this study is the combined price of concrete and steel. For this purpose, the average current price of concrete and steel in Tripoli is considered. As of 22nd October 2016, the average price of ready-mix concrete in batching plants in Tripoli was 132 Libyan Dinars (LD) per cubic meter. And the average price of reinforced steel bars in Tripoli was 1010 LD per 1000 kg (1 tonne). According to these prices, Table (4) shows the final comparison of combined prices of concrete and steel for each type of slab according to different codes. From this table, it can be seen that BS code requires the least total price for all types of slabs compared to other codes. This is because the volume of concrete and amount of steel reinforcement required by BS code was lesser than other codes for all types of slabs. On the other hand, ACI code gave the 2nd best price for one-way solid slab and flat plate, while the 2nd best price for two-way solid slab and one-way ribbed slab was given by EC2.

Table (4) Comparison Based on Cost

ACI					
Slab Type	Concrete Volume (m^3)	Unit Price (L.D)	Steel Weight (kg)	Unit Price (L.D)	Total Price (L.D)
One-Way	124.56	132	8551.13	1.01	25078.56
Two-Way	128.76	132	16016.52	1.01	33173.01
Flat Plate	129.60	132	9298.98	1.01	26499.17
One-Way Ribbed Slab	108.32	132	10048.80	1.01	24447.53
BS					
Slab Type	Concrete Volume (m^3)	Unit Price (L.D)	Steel Weight (kg)	Unit Price (L.D)	Total Price (L.D)
One-Way	94.56	132	9894.95	1.01	22475.82
Two-Way	92.76	132	9874.71	1.01	22217.78
Flat Plate	124.80	132	8384.89	1.01	24942.34
One-Way Ribbed Slab	69.12	132	9309.79	1.01	18526.73
EC2					
Slab Type	Concrete Volume (m^3)	Unit Price (L.D)	Steel Weight (kg)	Unit Price (L.D)	Total Price (L.D)
One-Way	115.32	132	10843.48	1.01	26174.15
Two-Way	126.12	132	11078.60	1.01	27837.23
Flat Plate	124.80	132	10034.62	1.01	26608.57
One-Way Ribbed Slab	93.66	132	10046.30	1.01	22509.88

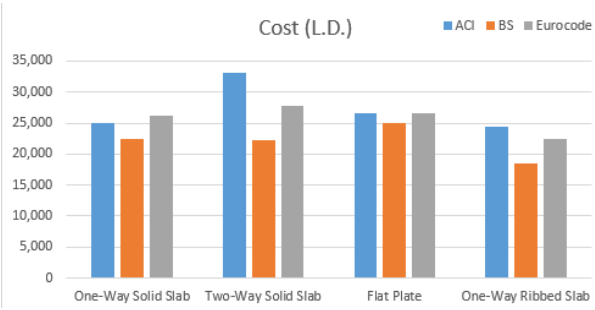

Fig. 11: Comparison Based on Cost

Conclusions

From the results of this study the followings can be concluded:

1. ACI code gives less deflection for all types of slabs. It gives 8.5% to 212.5% less deflection than BS code and 8.5% to 108.3% less deflection than EC2.
2. BS code is the most economical based on concrete volume compared to other codes. It requires 3.8% to 56.7% less concrete than ACI code and up to 35.5% less than EC2. On the other hand, EC2 requires 2.1% to 15.7% less concrete than ACI code.
3. BS code also requires less amount of reinforcement than other codes. It requires in average 15.6% less reinforcement than ACI code and 10.6% less than EC2.
4. Based on the total price, BS code leads to the lowest total price compared to other Codes. It requires 6.2% to 49.3% less price than ACI code and 6.7% to 25.3% less than EC2.
5. ACI code requires more reinforcement and concrete, which leads to greater total price but it gives less deflection. On the other hand, BS code gives less total price but more deflection.

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