Introducing an Economic Plan of Optimum Designing in the Joist Floor Slabs Construction

Dr. Ahmad Akbarlou

Faculty of Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran
E-mail: Ahmad.akbarlou@ymail.com

Abstract: In the present paper, considering joisted floor overuse in most of the residential, office and other types of buildings, numerous researches have been carried out into technical and theoretical problems. The results have been compiled as article and it has become clear that there is a drastic gap concerning financial matters of a variety of structures in building regulations. A steel building with joisted floor was considered to commence this technical and economic research. The effect of shifting floor framing direction of the joists on floor spans has been calculated and compared (frist on big span, next on small span) in the amount of used steel including the main steel girder weight and used bar weight in joist and the total cost of floor construction calculated according to it. The results show that in the case of building with joisted floor along the big span of floor span (from both direction of framing), 10% - 39% and 8% - 28% are saved in the case of steel use and floor construction costs, respectively. According to statistics concerning the city of Tabriz, 22000 tons of steel on average and about 440 billion Rials that is equal to 19.8 million $ would be saved in the cost of floor construction. These amounts of saving for the whole country(for Iran) are 580000 tons of steel and 12000 billion Rials that is equal to 540 million $.
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Key words: Joisted floor, optimal choice of framing direction, optimal steel use, financial saving.

1. Introduction

Utilizing joisted floor in country buildings is a common task because of its advantages such as using less steel, concrete, framing, possibility of manual installation, being thermal insulator, less weight, quick installation, and reasonable strength.

This study deals with the uncontrolled steel use in order to save financial expenses in building industry. This seems to be necessary because of the increasing demands of the society for appropriate building construction with less total cost.

On the other hand, because of insufficient technical and economical studies in the field of building construction methods mainly residential buildings, this research method may play a role in changing research issues and methods. Although quality and strengthen of structures, have been improved, it is obvious that less attention has been paid to the engineering economy. So far, no regulations or codes have been compiled and published by technical organizations or legal authorities. Moreover, uncontrolled and exceptional use of steel in country buildings, leading to increasing need for steel importation and expense increment, shows this research matters importance.

In the present paper, it has been proposed that related organizations such as Housing and Urbanization Organization, Engineering Constitution, etc., should care about economic matters in designing and constructing of building in addition to inspection problems, quality control and theoretical problems through compiling necessary regulations and codes.

2. Research Method

A residential building with steel structure and joisted floor, according the following plan, in two modes of framing, i.e. modes a and b, has been selected. After floor designing, the weight of used steel in the main girder and bar of the joist estimated and total weight of used steel has been calculated and compared in two cases of a and b. Then the costs of floor construction including the cost of main girder and joisted floor have been calculated and compared with to the price list of the year 2010 (the last official prices) that exchanged to the prices of year 2012.

In floor calculations, the design of steel girder considering vertical loads has been done by allowable stress method and based on Iranian steel code. The joist has been designed by ultimate strength method based on the code CP 110, rule 54/1405, dated on 97/06/12 (leaflet no.94) published by strategic planning and supervision organization.

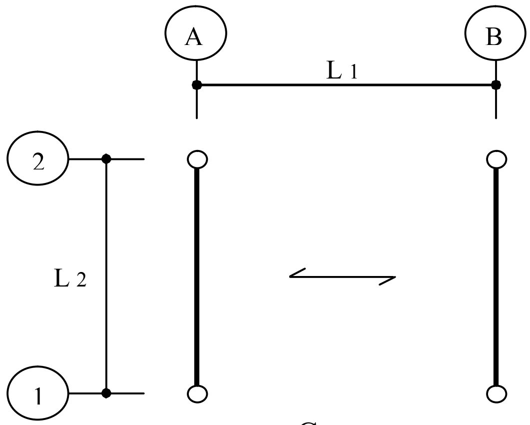
Case a) the main steel girder in axes A and B, and the direction of floor joist in L1 direction are as following figure ($L_1>L_2$)
Case b) the main steel girder in axes 1 and 2, and the direction of floor joist in L2 direction are as following figure ($L_1>L_2$)

4- Floor elements design and total cost of their preparation and construction.

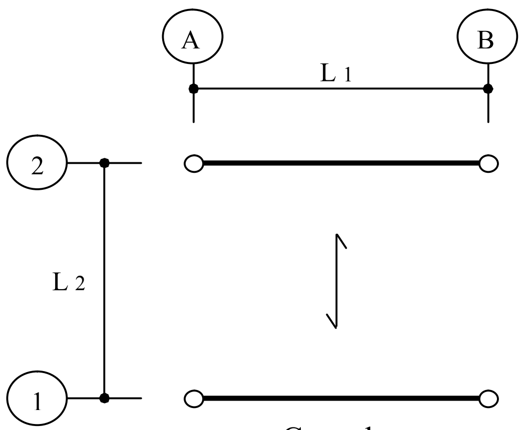
The study continues as follows with an example.
L_1=5 m , L_2=3 m
PL=650 kg/m^2 , LL=200 kg/m^2

Case a:

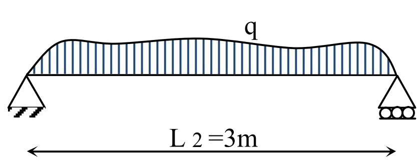
1-1-a: Design of steel girder in case (a), with a span of L_2=3m.



Case a



Case b



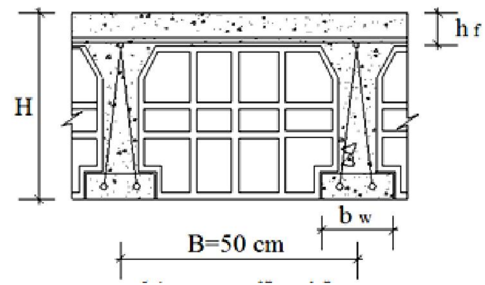
$$q = (650+200)?\frac{5}{2} \quad 2125\, {}^{kg}/_{m}$$

$$M = \frac{qL^2}{8} = \frac{2125?\ \ ^2}{8} = 2391\, kg.m$$

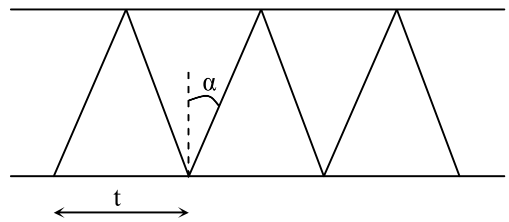
$$W = \frac{M}{F_b} = \frac{239100}{1584} = 151\, cm^3 \quad use: \ IPE\ 18$$

$G_1 = 6?\ 8.8 = 113\, kg$ the weight of main steel girders .

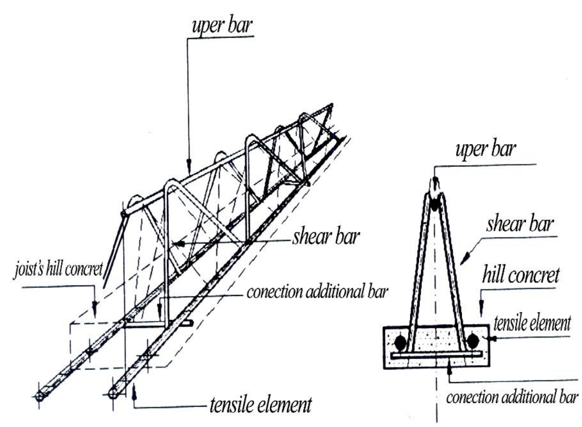
1-2- a: Design of the floor joist (tensile bar) in case (a), with a span of L_1=5m.



Section of the joisted floor



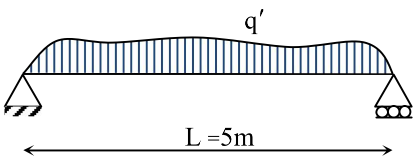
Stirrup **section**



Defining of the signs	
$L = 5\, m$	**Joist span**
$H = \frac{L}{20} = 25\, cm$	**Thickness of floor**
$h_f = 5\, cm$	**Thickness of concrete slab**
$b_w = 10\, cm$	**Width of heel**
$h_e = 230\, cm$	**Effective height**
$Z = 0.9 h_e$	**Elastic arm**
f_{cu}	**compressive stress of the joist concrete**
$t = 20\, cm$	**The distance of stirrups**
$f_y = 4200\, {}^{kg}/_{cm^2}$	**tesile bar yield stress**
$\sigma_a = 1400\, {}^{kg}/_{cm^2}$	**Stirrup allowable stress**
$f_c = 200\, {}^{kg}/_{cm^2}$	**28- day concrete compression**

strength	
$\alpha = 58^o$	**Stirrup's angle**
B = 50 cm	**Distance of the joists**
$A_1 = A_S =$	**tensile bar Area**

Design based on the USD (ultimate stress design) method using CP110 code:



$q' = (1.4DL + 1.6LL)?\ .5$

$q' = (1.4?\ \ 50 + 1.6?\ \ 00)?\ .5 = 615\ {kg}/{m}$

$M = \frac{q' L^2}{8} = \frac{615?\ \ ^2}{8} = 1922\ kg.m$

$M_u = 0.87F_y A_s \left(h_e - \frac{h_f}{2} \right)$

$192200 = 0.87?\ \ 200諸\ _s ? \left(3 - \frac{5}{2} \right)$

$A_s = 2.57\ cm^2$ use 2Φ14 AIII

$M_u = 0.4f_{cu} Bh_f \left(h_e - \frac{h_f}{2} \right)$

$192200 = 0.4 論_{cu}\ ?\ \ 0?\ \ ? \left(3 - \frac{5}{2} \right)$

$f_{cu} = 94\ {kg}/{cm^2} < 200\ {kg}/{cm^2}$ o.k.

2-2-a: Design of joist stirrups using ASD (Allowable stress design) method

$q' = (DL + LL)?\ .5 = 425\ {kg}/{m}$

$\alpha = 58^o \qquad V_{max} = \frac{q' L}{2} = 425?\ \frac{5}{2} \quad 1063\ kg$

$\tau = \frac{V_{max}}{Z.b_w} = \frac{1063}{0.9?\ \ 3?\ \ 0} = 5.14$

$5.14 > 4.2 kg/cm^2$ Stirrup is need

$$A_2 = \frac{V.t}{Z.\sigma_0 (sina + cosa)}$$

$$A_2 = \frac{1063 \times 20}{1400 \times 0.9 \times 23 \times (0.85 + 0.53)}$$

$A_2 = 0.53 cm^2$ use Φ8

3-2-a: Design of compressive bar according to the code.

A_3 : use Φ10

4-2-a: Thermal bar perpendicular to joist direction.

$A_4 = \frac{1.75}{1000}$? Concrete slab Area

$A_4 = \frac{1.75}{1000}?\ \ 00?\ \ = 0.875\ cm^2$

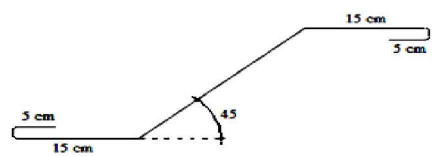
use $4Φ6\ /m$

5-2-a: design of thermal bar parallel to joist direction.

$A_5 = \frac{1.25}{1000}?\ \ 00?\ \ = 0.625\ cm^2$

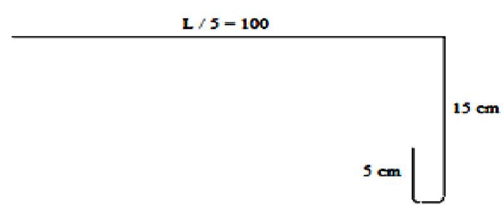
use $2Φ6\ /m$

6-2-a: Shear reinforcing bar



A_6 : use Φ8 L = 75cm

7-2-a: Negative moment bar



$A_7 = 0.15A_S$

$A_7 = 0.15?\ \ ?\ .54 = 0.46\ cm^2$

use Φ8 L = 120 cm

8-2-a: Joist rib bar

Live load $q'' = 200 < 350$, $L > 4\ m$

$A_8 = \frac{1}{2} A_S = \frac{1}{2}?\ \ ?\ .54 = 1.54$ use 2Φ10

9-2-a: Calculating the weight of bar used in joist

Table 1: Calculating the weight of bar

POS	ϕ / Φ	N	L	G (kg/m)	W (kg)
A_1	Φ14 AIII	12	5	1.21	**72.6**
A_2	Φ8 AI	6	5×2.5	0.395	**30**
A_3	Φ10 AII	6	5	0.617	**18.5**
A_4	Φ6 AI	20	3	0.222	**13.3**
A_5	Φ6 AI	6	5	0.222	**6.7**
A_6	Φ8 AI	12	0.75	0.395	**3.6**
A_7	Φ8 AII	12	1.2	0.395	**5.7**
A_8	Φ10 AII	2	3	0.617	**3.7**

Weight (AI = 54 kg, AII = 28 kg, AIII = 73 kg)
Total weight of bar = 113 kg
Total steel use = 155kg

Case b:

1-1-b: design of steel girder in mode b with span of L_1=5m.

$$q = 850 ? \ .5 = 1275 \ {}^{kg}/_{m}$$

$$M = \frac{1275 ? \ ^2}{8} = 3984 \text{ kg.m}$$

$$W = 252 cm^3 \qquad \Rightarrow \text{use} \quad IPE22$$

$$G_2 = 10 ? \ \ 6.2 = 262 \text{ kg}$$

10-2-a: Calculating the cost of providing and constructing the floor using Iranian price list of construction field published in 2009(the last official price list)

Table 2:

Row	Operation description	number of price list	unit	amount (kg)	unit price (Rial)	Total price (Rial)
1	Providing and executing of AI bar	070101	kg	54	8980	484920
2	Providing and executing of AII bar	070201	kg	28	8000	224000
3	Providing and executing of AIII bar	070205	kg	73	6360	464280
4	Additional price of joist truss	070301	kg	122	145	17690
5	Providing and executing of joisted floor whit 25 cm thickness	100102	m^2	15	122000	1830000
6	Providing and executing of bearing girder	090211	kg	113	8830	997790
Sum of total value=4018680× 1.8 = 7233624						

The exchange coefficient of prices of year 2010 - 2012 based on the cost coefficient and daily prices = 1.8

1-2-b: design of floor joist (tensile bar) in mode b with span of L_2=3m.

$$q = 615 \ {}^{kg}/_{m} \qquad M = \frac{615 ? \ ^2}{8} = 692 \text{ kg.m}$$

$$M_u = 0.87 ? \ \ 200 諸 \ _S ? \left(\ 3 - 2.5 \right)$$

$$A_1 = A_S = 0.92 \ cm^2$$

use 2Φ8 AIII

2-2-b: design of joist stirrup using ASD (Allowable stress design)method.

$$q' = 425 \ {}^{kg}/_{m}$$

$$V = 425 ? \ \frac{3}{2} \quad 638 \text{ kg}$$

Shear stress :

$$\tau = \frac{638}{0.9 ? \ \ 3 ? \ \ 0} = 3.1 < 4.2 \ {}^{kg}/_{cm^2}$$

According to the code :

$$A_{min} = 0.0015 \, b_w \ t = 0.0015 ? \ \ 0 ? \ \ 0 = 0.3 \ cm^2$$

use A_2 = Φ6 AI

3-2-b: design of compressive bar according to the code.

A_3 : Φ8 AII

4-2-b: thermal bar perpendicular to joist

A_4 : 4Φ6/m AI

5-2-b: design of thermal bar parallel whit joist

$A_5 \ : \ 2\Phi6 \diagup_{m} \ AI$

6-2-b: shear reinforcing bar

$A_6 \ : \ \Phi8 \ AI \quad L = 75\,cm$

7-2-b: negative moment bar

$A_7 \ : \ 0.15A_1 = 0.15? \ ? \ .5 = 0.15\,cm^2$

use $\Phi6$ AII

8-2-b: Joist's rib bar:

according to the code joist's rib is not need.

$L = 3 < 4$

9-2-b: Calculating the weight of the bar used in the joist.

Table 3

POS	$\phi \diagup \Phi$	N	L	G (kg/m)	W (kg)
A_1	Φ8 AIII	20	3	0.395	**24**
A_2	Φ6 AI	10	3×2.5	0.222	**16.7**
A_3	Φ10 AII	10	3	0.395	**12**
A_4	Φ6 AI	12	5	0.222	**13.3**
A_5	Φ6 AI	10	3	0.222	**6.7**
A_6	Φ8 AI	20	0.75	0.395	**5.9**
A_7	Φ6 AII	20	0.8	0.222	**3.6**

(AIII = 24 kg)و (AII = 16 kg)و (AI = 43 kg)

Total weight of bar = 83 kg

10-2-b: Calculating the cost of providing and constructing the floor with Iranian price list of construction field published in 2009

Table 4

Row	Operation description	number of price list	unit	amount (kg)	unit price (Rial)	Total price (Rial)
1	Providing and executing of AI bar	070101	kg	43	8980	386140
2	Providing and executing of AII bar	070201	kg	16	8000	128000
3	Providing and executing of AIII bar	070205	kg	24	6360	152640
4	Additional price of joist truss	070301	kg	53	145	7685
5	Providing and executing of joisted floor whit 25 cm thickness	100102	kg	15	122000	1830000
6	Providing and executing of bearing girder	090211	kg	262	8830	2313460
Sum of total price with operating overhead coefficient (Rial) = (4817925×1.8= 8672265)						

The exchange coefficient of prices of year 2010-2012 based on the cost coefficient and daily prices = 1.8. In the table 5 the weight of steel use for different spans is presented after designing and calculating like upper method.

Table 5: the weight of used steel and the percent of the steel use reduction in 10 modes with different spans and two different modes of joist position (a & b).

Row	Span of joist (m)	Span of the main girder (m)	Weight of used bar (kg)	Weight of used steel (kg)	Sum of the weight of steels (kg)	Decrease percent of steel use	$L_2 \diagup L_1$
1	3	4	71	179	250		1.33
	4	3	83	113	196	%22	
2	3	5	83	262	345		1.67
	5	3	155	113	268	%22	
3	3	6	105	433	538		2
	6	3	196	134	330	%39	
4	3	7	123	591	714		2.33
	7	3	315	134	449	%37	
5	4	5	164	361	525		1.25
	5	4	196	246	442	%16	
6	4	6	197	506	703		1.5
	6	4	262	246	508	%28	
7	4	7	230	687	917		1.75
	7	4	420	289	709	%23	
8	5	6	293	589	882		1.2
	6	5	320	422	742	%16	
9	5	7	342	799	1141		1.4
	7	5	525	491	1016	%11	
10	6	7	460	928	1388		1.17
	7	6	624	685	1300	%6	

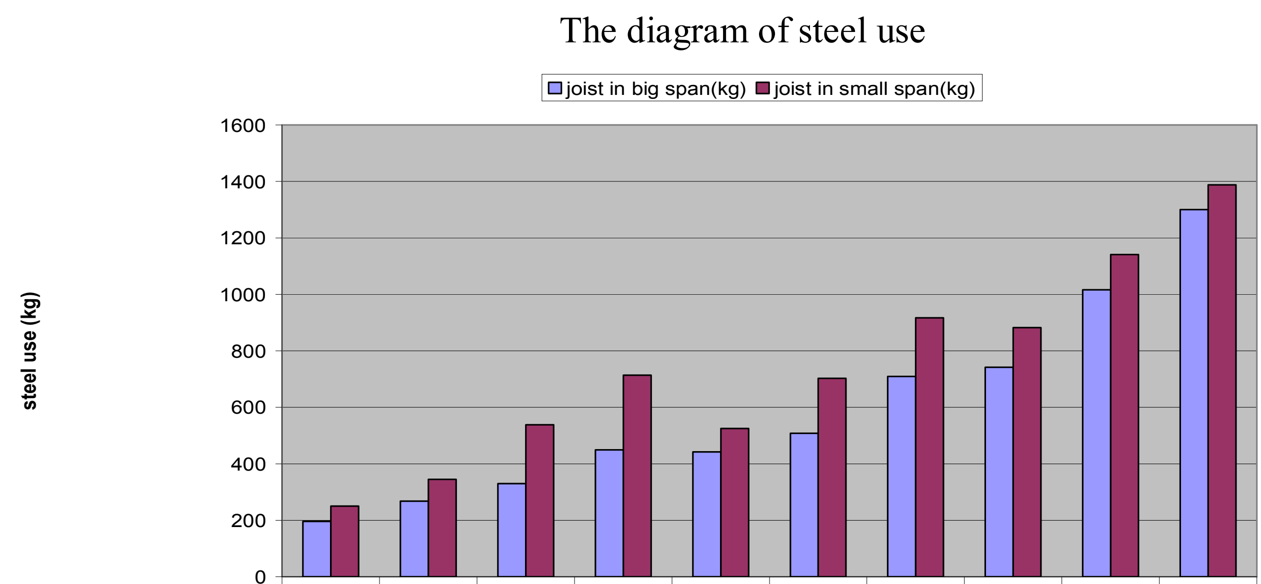
In the plan of the joists and girders, L_2 is the bigger span and L_1 is the smaller span.

Table 6: calculating the cost of construction of the floor.

Row	Joist 's span (m)	main girder span (m)	Total cost of the floor (Rial)	Percent of the cost decrease	L_2/L_1
1	3	4	5820327		1.33
	4	3	4951330	%15	
2	3	5	7829127		1.67
	5	3	6530355	%17	
3	3	6	7052700		2
	6	3	11327326	%28	
4	3	7	12495395		2.33
	7	3	11041051	%24	
5	4	5	11389071		1.25
	5	4	9952431	%13	
6	4	6	14768331		1.5
	6	4	11821657	%20	
7	4	7	18769642		1.75
	7	4	16702715	%11	
8	5	6	18448475		1.2
	6	5	16472216	%11	
9	5	7	24975127		1.4
	7	5	22950756	%8	
10	6	7	30274466		1.17
	7	6	27956667	%8	

In the plan of the joists and girders, L_2 is the bigger span and L_1 is the smaller span.

5 - The diagram of comparing steel use in different modes of floor framing:



	4*3	5*3	6*3	7*3	5*4	6*4	7*4	6*5	7*5	7*6
joist in big span(kg)	196	268	330	449	442	508	709	742	1016	1300
joist in small span(kg)	250	345	538	714	525	703	917	882	1141	1388

Diagram 1: the curve of steel use.

The upper diagram indicates that in all cases when joist is located in bigger span, the use of steel decreases considerablely.

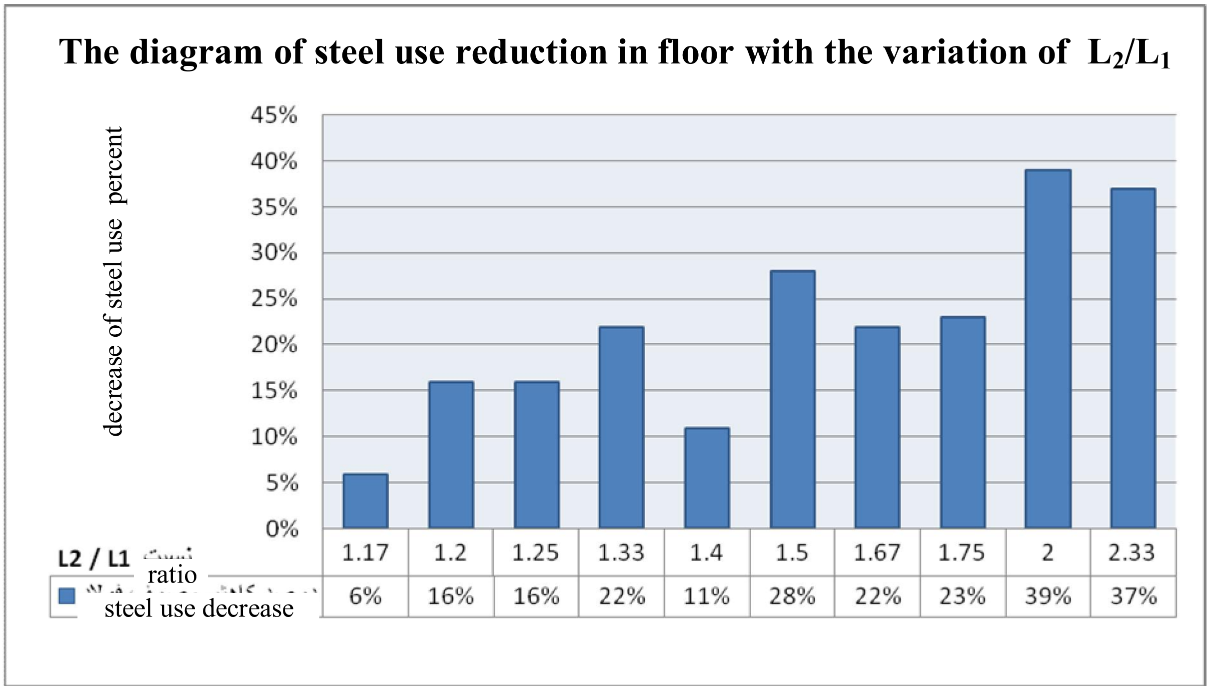


Diagram 2: The curve of steel use reduction with the variation of L_2/L_1

As it is seen, when the ratio of L_2/L_1 increases, steel use percent decreases.

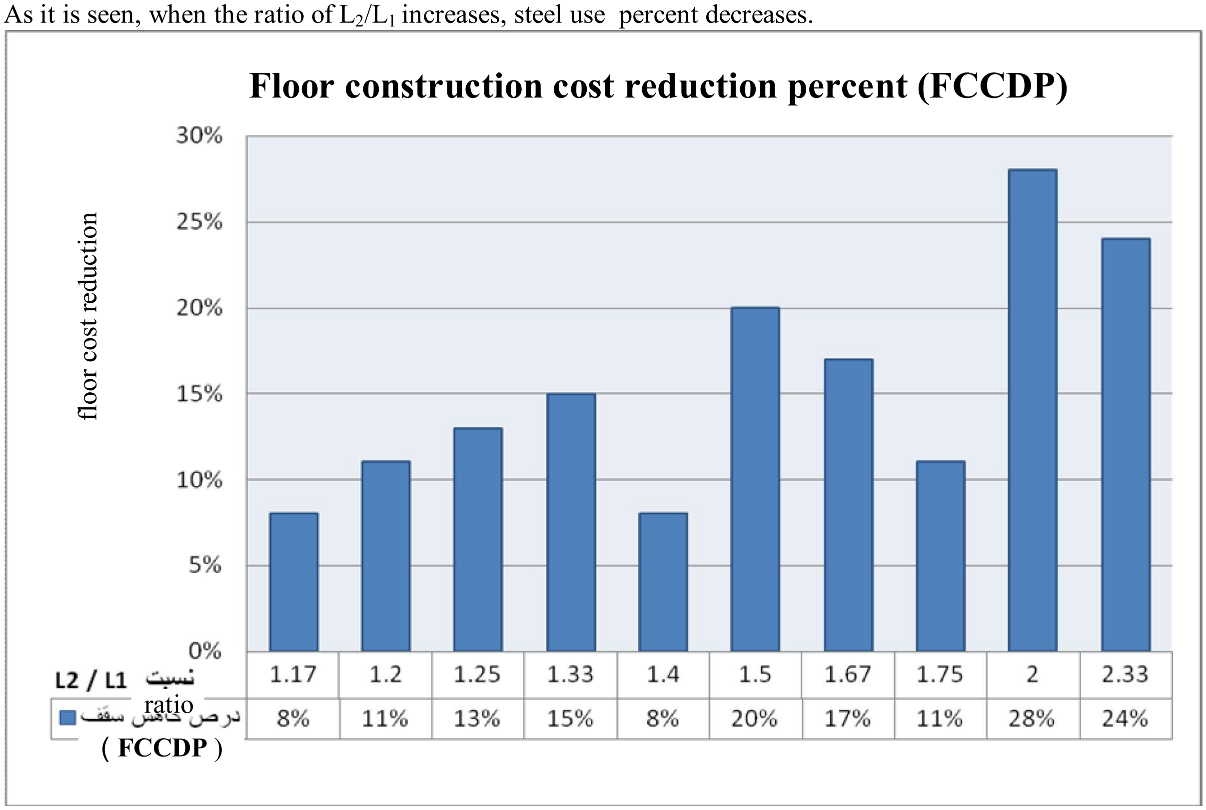


Diagram 3: Floor cost reduction percent (FCCDP)

As the above diagram indicates, by increasing L_2/L_1 ratio, floor construction cost percent decreases (except two cases).

5. Conclusions

1) All the studied cases being the common spans used in joisted floor have been compared with the obtained results on diagram (1) which indicates that when the joist is constructed on the big span, steel use decreases considerably.
2) Considering diagram 2, it can be observed that when L_2/L_1 (ratio of big span to small span) increases, the steel use decreases, and when L_2/L_1= 2, the maximum decrease can be observed.
3) Considering diagram (3), it can be deduced that in all cases when the joist is designed on the big span, the cost of joisted floor construction decreases.
4) Based on the obtained results on diagram (3), when L_2/L_1 increases, the cost decreases; and the maximum decrease is when L_2/L_1=2.
5) Economical result of the research:
6) The average amount of steel reduction (22%) and the average amount of the floor cost reduction (16.5%) can be obtained from diagram (3).

Through calculating the average amount of used steel in joisted floor which is 26 kg/ m^2, 6.4 kg less steel will be used per squre meter of joisted floor. Therefore, according to the statistics on average building construction of the one year for a city such as Tabriz, there has been more than 3500000 square meter and assuming 98% of construction whit joisted floor, 22000 tons of steel would be saved which amounts to 440 billion Rials saving(equal to 20 million $). Thus, for the whole country(for Iran) it would be 580000 tons of steel use reduction and 12000 billion Rials saving(equal to 540 million $). With such saving for a city such as Tabriz, we can construct 1500 residential building units, and for the whole country about 40000 residential building units, each unit with 80 m^2 of area.

Therefore, with serious attention to this plan, there will be less need to steel importation and there will be huge savings on cost of constructing the buildings.

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11/16/2012