Comparison of ConTruss voided slab with Waffle system

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Contents

Introduction:

The use of innovative technologies as well as optimizing methods in constructions have been developed in recent years. One innovative system practiced in constructing of slab is Contruss voided slab system, which was issued and certified in 2014. In this report, waffle slab system will be illustrated and compared to the Contruss voided slab system, from technical and economic point of views.

1- Waffle slab introduction

Due to the weak operation of concrete in tension, all of the constructed concrete systems were come up with a solution to eliminate unloadable concrete in structures during previous centuries.

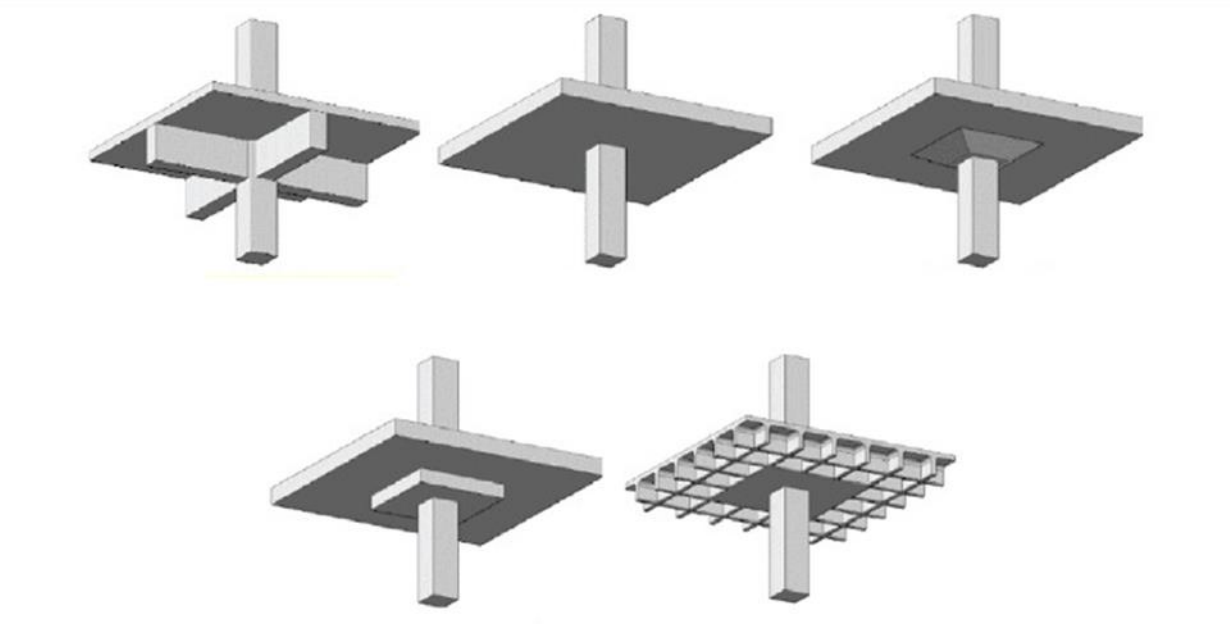


Figure 1.1. Optimizing manners of concrete slab

By unloading the concrete via temporary cuboid fillers as well as increasing ceiling thickness, waffle system will increase moment of inertia of the slab in horizontal direction and distribute the loads in two trajectories through T-shaped ribs. Based on including T-shaped ribs, waffle slab function is similar to the rib and block slab tutorial, but the difference is that waffle slab will operate as a two-way system.

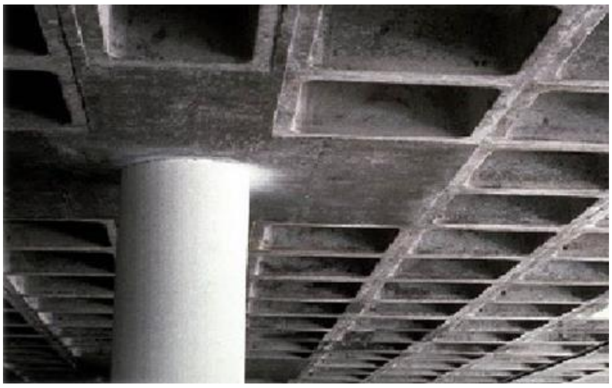



Figure 1.2. Waffle slab

2- Economic comparison

2-1- High cost of initial purchase of waffle fillers:

Waffle slab fillers are made of metal or plastic that should be practiced several times in constructing of ceiling. Economically, the fillers must be used for several ceilings because the Initial purchase of the fillers will cost much. Therefore, applying waffle systems in small building projects is not economical.

On the contrary, a double-sided voided slab system by the Contruss permanent filler is capable to be practiced for all types of ceilings with various conditions.

Figure 2.1. Waffle slab formwork

2-2- Increase in cost because of sub-constructing of the ceiling:

Bottom surface of waffle ceiling will remain hollow and pitted after installation but the Contruss system presents a flat soffit with smooth bottom surface of ceiling, which will result in lack of reinforcement mesh and dropped ceiling in some places. Many places are not required to be sub-constructed such as parking lots and bedrooms, only painting and plastering will be needed due to the lack of systems.

Figure 2.2. Bottom surface of Contruss and waffle ceiling

2-3- Increased thickness of ceiling:

In the Contruss system, total thickness of ceiling will be less than waffle slab. The reasons can be evaluated from two aspects. First, the Contruss system includes I-shaped ribs that will provide higher moment of inertia compared to T-shaped ribs in waffle system. Moreover, unlike to the smooth bottom surface of slab in the Contruss system, the bottom surface of waffle slab will be hollow and pitted, which will require Sub-construction as well as dropped ceiling installation, leads to increased total thickness of the ceiling.

Figure 2.3. Contruss voided slab system

Figure 2.4. Waffle voided slab system

On the other hand, by including two concrete layers and perpendicular shear webs, Contruss system forms a high rigid slab that will operate properly subjected to seismic loads. Additionally, by providing shear walls in the structure, a flat soffit will be created under of ceiling as depicted in figure 2.3.

3- Technical comparison

3-1- Calculating moment of inertia:

In many design including long spans, the height of slab is highly influenced by ceiling deflection control, which is directly related to the moment of inertia of the ceiling. Therefore, the moment of inertia is an important factor in the ceiling. In addition, for tall structures with high drift ratios, the moment of inertia will be a significant factor in controlling displacements.

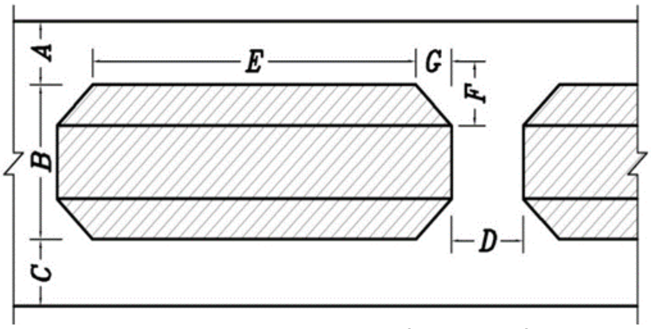


Figure 3.1. Schematic image of Contruss filler

B (mm)	*H (mm)*	*D (mm)*	*number of modules per meter*	*number per square meter*	*Total slab Volume ($x10^6$ mm^3)*	*Conruss Volume ($x10^6$ mm^3)*	*Volume of hollow slab ($x10^6$ mm^3)*	*I total slab ($x10^9$ mm^4)*	*I contruss ($x10^6$ mm^4)*	*I hollow slab ($x10^9$ mm^4)*
130	280	100	1.54	2.37	280E	34	199	1.8	88.3	1.7
150	*300*	*100*	*1.54*	*2.37*	*300*	*40*	*205*	*2.3*	*137*	*2*
190	340	100	1.54	2.37	340	52	216	3.3	283	2.8
240	390	120	1.49	2.23	390	67	240	4.9	579	4.1
320	470	140	1.45	2.10	470	92	278	8.7	1400	6.6
400	550	160	1.41	1.98	550	116	320	13.9	2800	10

Table 1. Moment of inertia and volumes of Contruss filler

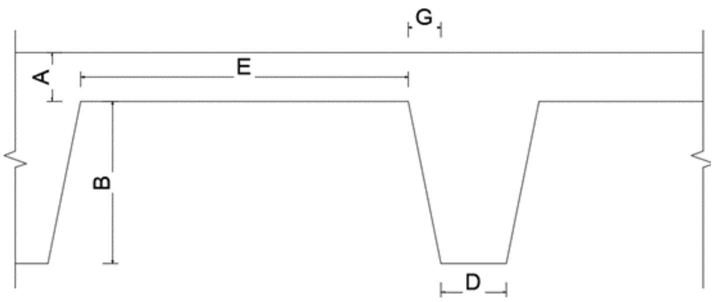


Figure 3.2. Schematic image of waffle system

B (mm)	*H total (mm)*	*D (mm)*	*Number of modules per meter*	*number per square meter*	*Total slab Volume ($x10^6mm^3$)*	*Waffle Volume ($x10^6mm^3$)*	*Volume of hollow slab ($x10^6mm^3$)*	*I total slab ($x10^9mm^4$)*	*I Waffle ($x10^9mm^4$)*	*I hollow slab ($x10^9mm^4$)*
180	260	100	1.61	2.60	260	45	143	2.2	1.0	0.51
240	320	100	1.61	2.60	320	59	167	4.0	1.9	0.97
300	380	120	1.56	2.44	380	72	204	6.2	2.8	1.8
400	480	140	1.52	2.30	480	94	264	11.6	5.2	3.8
450	530	160	1.47	2.16	530	104	305	14.9	6.5	5.4

Table 2. Moment of inertia and volumes of Contruss filler

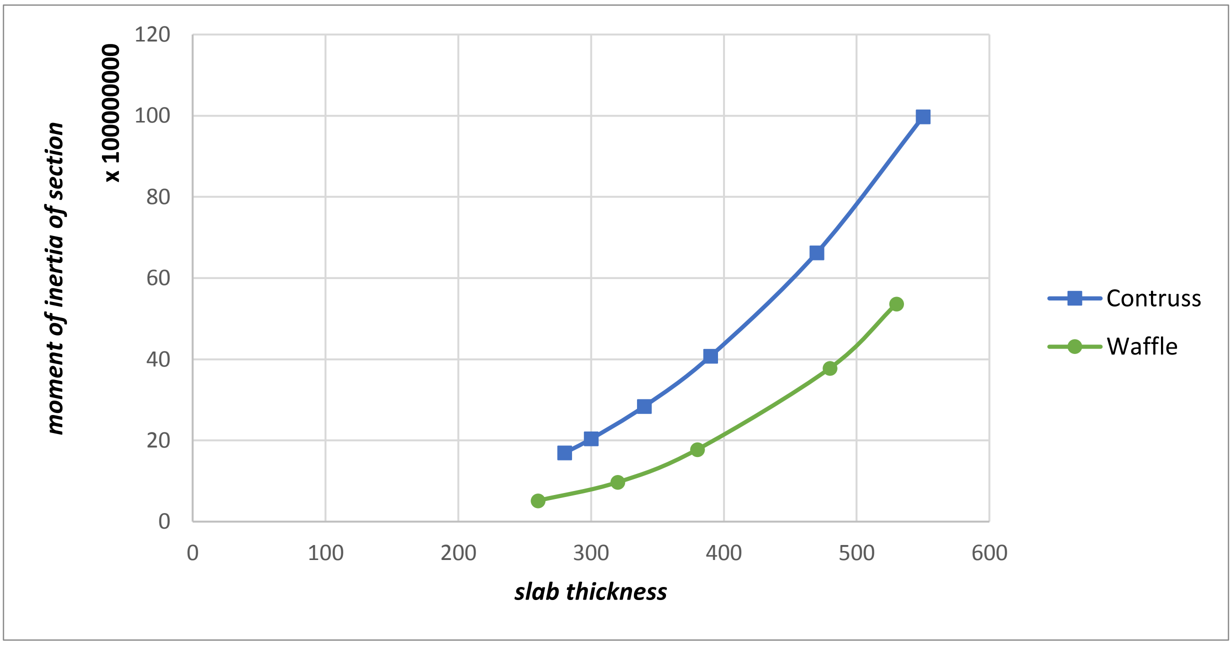


Diagram 1. Moment of inertia of section- slab thickness

By considering various dimensions of Contruss and waffle fillers, the moment of inertia of the section has been calculated according to the slab weight and presented in diagram 2.

H (mm)	D (mm)	I hollow slab ($x10^9mm^4$)	Volume of hollow slab ($x10^6mm^3$)	Load Slab Dead (kg/m^2)	Area of Contruss ($x10^3mm^2$)	total Area ($x10^3mm^2$)	Area of hollow slab ($x10^3mm^2$)	F modifier	stiff/weight $x10^6$
280	100	1.7	199	498	66.5	280	177	0.63	3.4
300	100	2.0	204	512	77.5	300	180	0.60	4.0
340	100	2.8	216	540	99.5	340	186	0.55	5.3
390	120	4.1	239	599	127	390	200	0.51	6.8
470	140	6.6	277	694	171	470	222	0.47	9.5
550	160	10.0	320	801	215	550	247	0.45	12.5

Table 3. Moment of inertia of section- Contruss slab weight

H total (mm)	D (mm)	I hollow slab ($x10^9mm^4$)	Volume of hollow slab ($x10^6mm^3$)	Slab Dead Load (kg/m^2)	Area of Waffle ($x10^3mm^2$)	total Area ($x10^3mm^2$)	Area of hollow slab ($x10^3mm^2$)	F modifier	stiff/weight $x10^6$
260	100	0.51	142	357	90.0	260	114	0.442	1.4
320	100	0.97	166	417	118	320	128	0.401	2.3
380	120	1.80	203	510	147	380	150	0.396	3.5
480	140	3.80	263	659	194	480	186	0.388	5.7
530	160	5.4E	305	763	216	530	212	0.401	7.0

Table 4. Moment of inertia of section- waffle slab weight

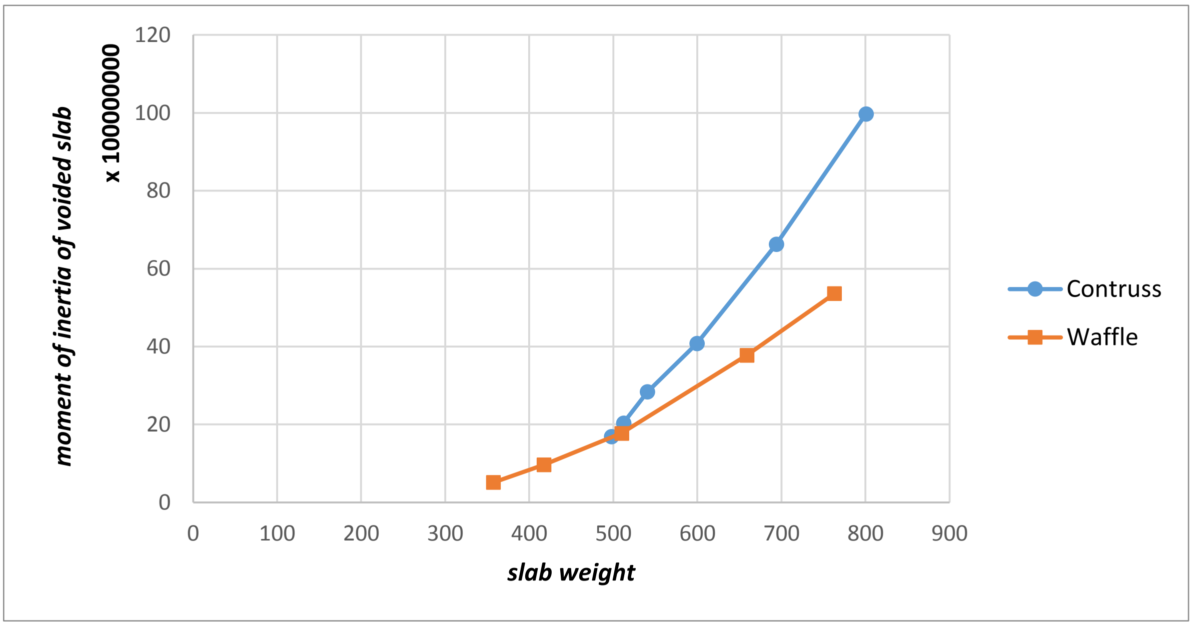


Diagram 2. Variation of moment of inertia- slab weight

Based on diagram 2, because of providing higher moment of inertia, the Contruss voided slab system will operate more properly subjected to flexure with equal weight. As regard to equal weight, it will be concluded that the costs of Contruss system is approximately equal to waffle system.

In diagram 3, the proportion of moment of inertia to weight ($\frac{I}{W}$) has been depicted according to various slab thicknesses. The diagram indicates that Contruss voided slab can provide more flexure strength with lower ceiling thickness.

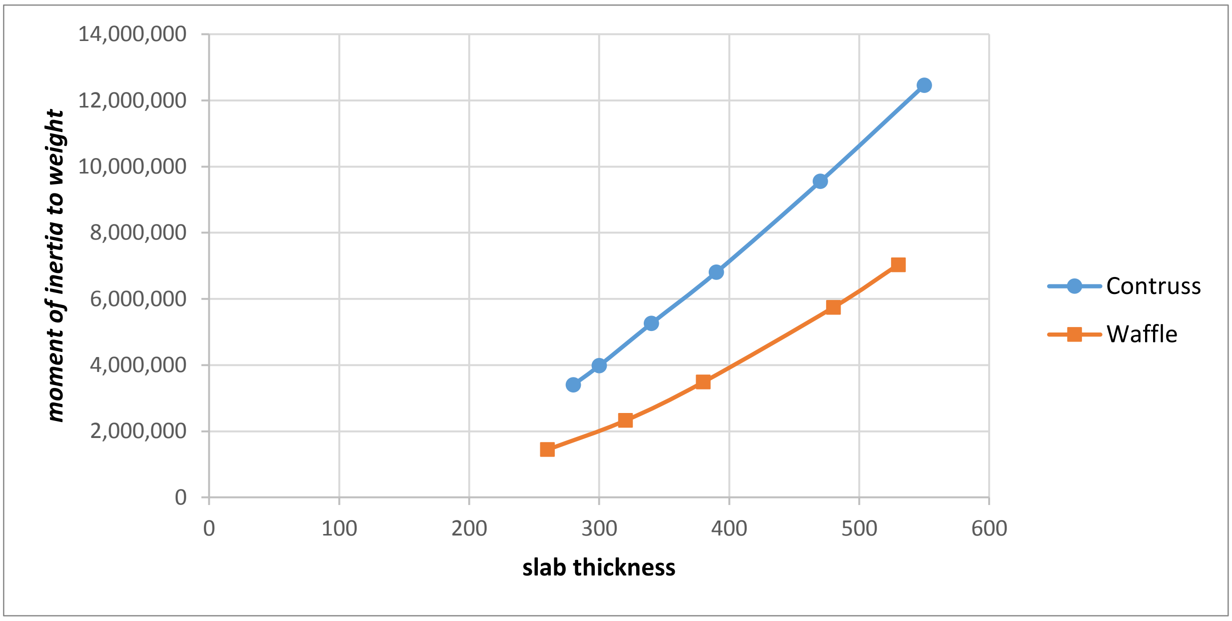


Diagram 3. Proportion of moment of inertia based on weight

3-2- Axial strength:

Although slab section is seldom subjected to axial forces, but as a rigid diaphragm, the slab function is so important particularly when it is supposed to operate as a shell element and the ceiling is supposed rigid. Axial strength of slab is depended on the cross section of voided slab, which will be more in the Contruss system, due to the larger cross section of Contruss voided slab compared to waffle system. For comparison of two systems in terms of axial strength, the factor of cross section has been used which is derived by dividing of ultimate cross section of slab to cross section of an equal solid slab.

Calculating the factor of cross section is in the tables 1,2. Based on the slab thickness, the factor of cross section is ranging from 0.45 to 0.53 for the Contruss system, but it is raging from 0.39 to 0.44 for waffle slab. The variation range of the factor is a good proof to demonstrate capability of Contruss system in optimized use of concrete but for more accurate evaluation, refer to diagram 1. As seen in the diagram, by practicing equal amount of concrete, the Contruss voided slab will create more appropriate section subjected to axial forces. This advantage is caused by use of optimized Contruss fillers in 3 dimensions. Based on the diagram, for spans beyond 7 meters, practicing of Contruss system will be more economical.

H total (mm)	D (mm)	number of modules per meter	total Area ($x10^3mm^2$)	Area of contruss ($x10^3mm^2$)	Area of hollow slab ($x10^3mm^2$)	F modifier	Slab Dead Load (kg/m^2)
280	100	1.54	280	67	178	0.63	498
300	100	1.54	300	78	181	0.60	512
340	100	1.54	340	100	187	0.55	540
390	120	1.49	390	127	200	0.51	599
470	140	1.45	470	171	222	0.47	694
550	160	1.41	550	215	247	0.45	801

Table 5. Weight and cross section of Contruss slab

H total (mm)	D use (mm)	Number of modules per meter	total Area ($x10^3mm^2$)	Area of Waffle ($x10^3mm^2$)	Area of hollow slab ($x10^3mm^2$)	F modifier	Slab Dead Load (kg/m^2)
260	100	1.61	260	90	115	0.44	357
320	100	1.61	320	119	128	0.40	417
380	120	1.56	380	147	150	0.40	510
480	140	1.52	480	194	186	0.39	659
530	160	1.47	530	216	212	0.40	763

Table 6. Weight and cross section of waffle slab

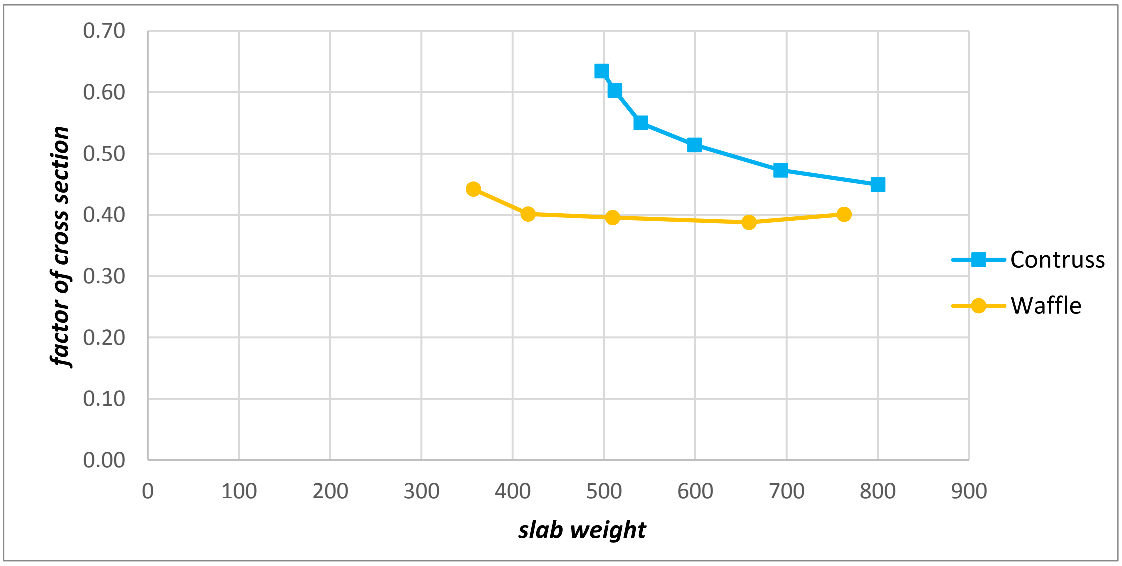


Diagram 4. Factor of cross section- slab weight

3-3- Flexural strength:

Flexural strength of a slab is a factor that implies economic level of slab design, because this factor is involved in controlling of deflection and tensions in most parts of the slab. In the following, bending capacity factor is practiced for comparison of flexural strength related to two voided slab sections. For calculating bending capacity of the slab, first it is supposed that 3 numbers of #14 rebar has been used at the top and bottom of shear web. The maximum positive bending moment of the section is calculated according to the tables 5,6.

H (mm)	Slab Dead Load (kg/m^2)	$A_{(3\phi14)}$ (mm^2)	$\bar{\rho}_{(t)}$ x10 -3	ρ_b x10 -3	$\bar{\rho}_b$ x10 -3	ρ_{min} x10 -3	a (mm)	M_n (N) x10^6
280	498	462	2.5	33	35.0	6.1	24.0	139
300	512	462	2.4	33	34.9	5.6	24.0	151
340	540	462	2.1	33	34.6	4.9	24.0	177
390	599	462	1.8	33	34.3	4.2	23.7	206
470	694	462	1.4	33	33.9	3.4	23.4	253
550	801	462	1.2	33	33.7	2.8	23.1	299

Table 7. Positive bending capacity of Contruss section

H (mm)	Slab Dead Load (kg/m^2)	$A_{(3\phi14)}$ (mm^2)	$\bar{\rho}_{(t)}$ x10 -3	ρ_b x10 -3	$\bar{\rho}_b$ x10 -3	ρ_{min} x10 -3	a (mm)	M_n (N) x10^6
260	357	462	2.9	33	35.4	6.9	24.5	122
320	417	462	2.3	33	34.8	5.5	24.5	161
380	510	462	1.9	33	34.4	4.4	24.2	198
480	659	462	1.5	33	34.0	3.4	23.8	258
530	763	462	1.3	33	33.8	3.0	23.5	286

Table 8. Positive bending capacity of waffle section

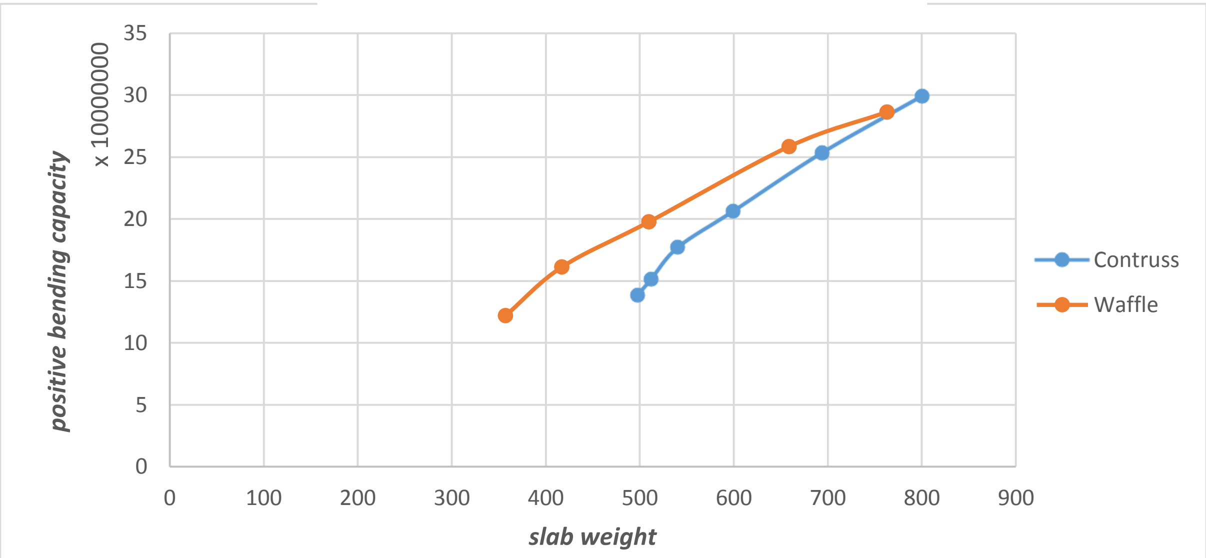


Diagram 5. Positive bending capacity - slab weight

As seen in the diagram, there is no considerable difference between positive bending capacity of two slabs, whereas there will be considerable difference about negative bending capacity according to tables 7,8.

H (mm)	Slab Dead Load (kg/m^2)	$\bar{\rho}_{(t)}$ x10 $^{-3}$	ρ_b x10 $^{-3}$	$\bar{\rho}_b$ x10 $^{-3}$	ρ_{min} x10 $^{-3}$	a (mm)	$M_n(N)$ x10^6
280	498	2.54	32.5	35	6.1	24.0	139
300	512	2.37	32.5	35	5.6	24.0	151
340	540	2.09	32.5	35	4.9	24.0	177
390	599	1.77	32.5	34	4.2	23.7	206
470	694	1.42	32.5	34	3.4	23.4	253
550	801	1.18	32.5	34	2.8	23.1	299

Table 9. Negative bending capacity of Contruss section

H (mm)	Slab Dead Load (kg/m^2)	$\bar{\rho}_{(t)}$ x10 $^{-3}$	ρ_b x10 $^{-3}$	$\bar{\rho}_b$ x10 $^{-3}$	ρ_{min} x10 $^{-3}$	a (mm)	$M_n(N)$ x10^6
260	357	21.1	32.5	54	25.2	48.7	47
320	417	15.3	32.5	48	18.4	48.0	64
380	510	11.8	32.5	44	14.3	47.3	92
480	659	8.51	32.5	41	10.4	46.6	135
530	763	7.29	32.5	40	9.0	45.9	165

Table 10. Negative bending capacity of waffle section

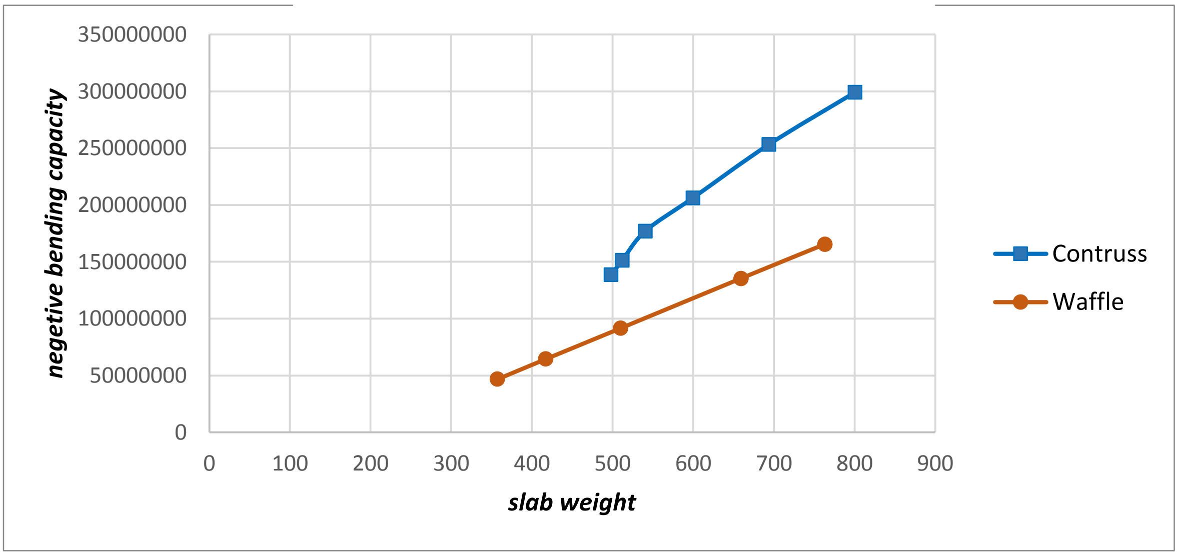


Diagram 6. Negative bending capacity – slab weight

As seen in the diagram, negative bending capacity of Contruss voided slab is significantly more than waffle slab, even by two times with equal weight in some cases. This difference will result in considerable reduction in use of negative reinforcement and also reduction in cracking as well as instantaneous and long-term deflections, which will ultimately lead to reduced construction costs.

3-4- Shear strength:

Shear strength of the section is highly related to shear webs of the slab, whereas in the vicinity of lateral bearing elements, variation of shear strength of the slab will be controlled by the act of removing middle voids. Shear strength is depended on the variability of horizontal dimension of the filler, which will be controlled suitably by the Contruss filler, due to solid nature of the fillers.

3-5- A case-comparison study of Contruss and waffle ceilings:

For comparison of two ceilings, a sample plan has been chosen as depicted in figure 3.3. Largest span is 12*12 square meters and Ceiling dead load of two systems are approximately equal. The Contruss ceiling includes fillers with height of 24cm and total height of the ceiling is as much as 39cm. Waffle ceiling includes fillers with height of 40cm and total height of the ceiling is 48cm.

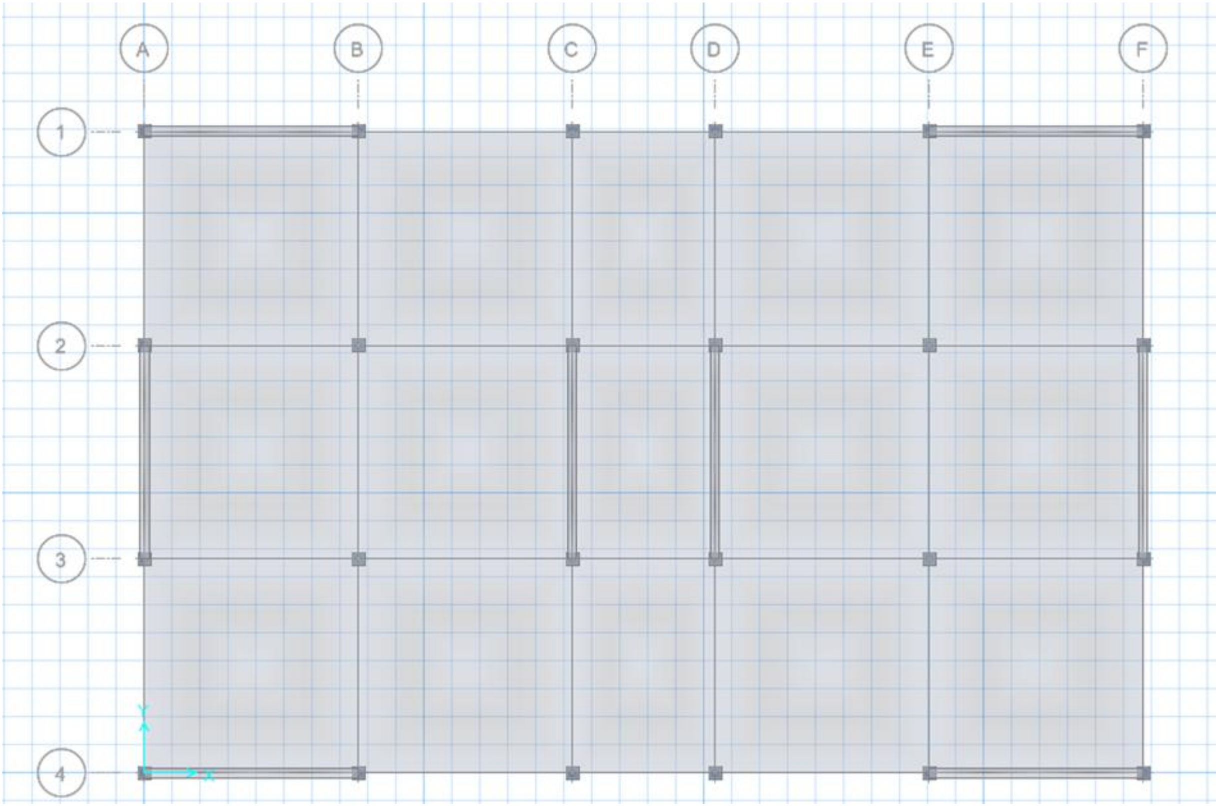


Figure 3.3. Sample plan

With regard to contour deformations depicted in figures 3.4 and 3.5, Contruss ceiling with higher rigidity and lower thickness, has less deformations compared to waffle ceiling.

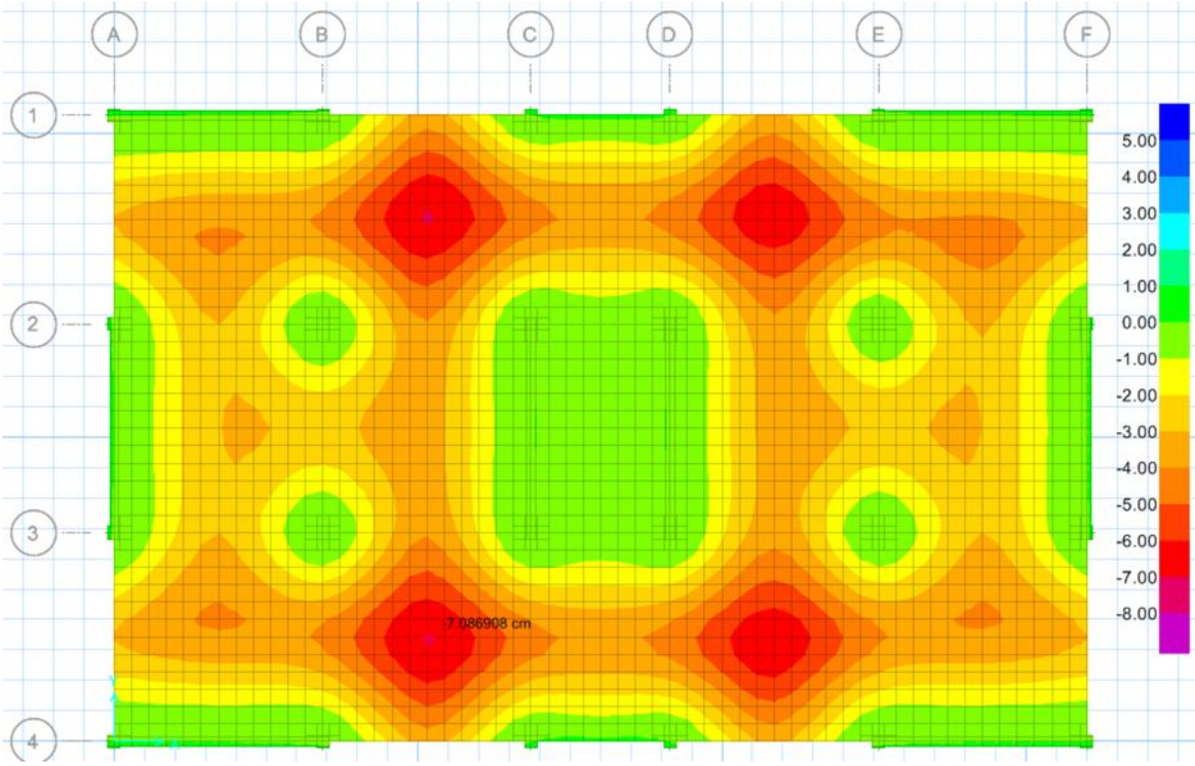


Figure 3.4. Contour deformations of Contruss slab

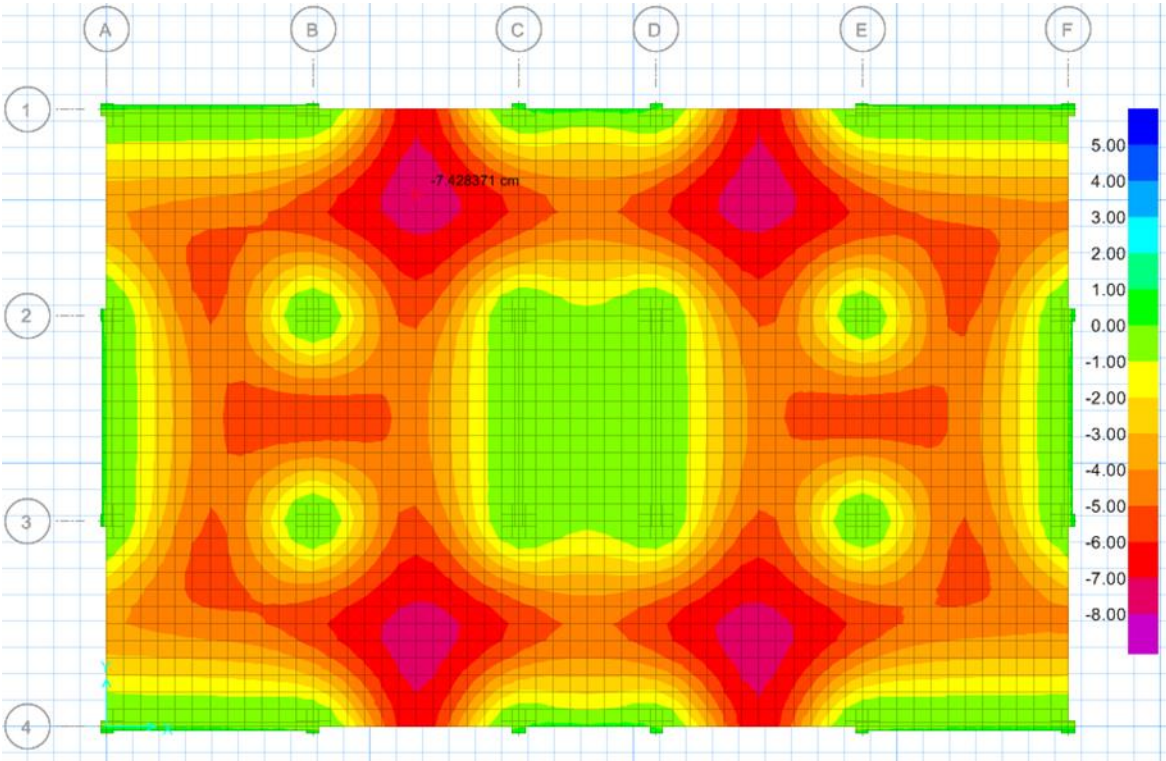
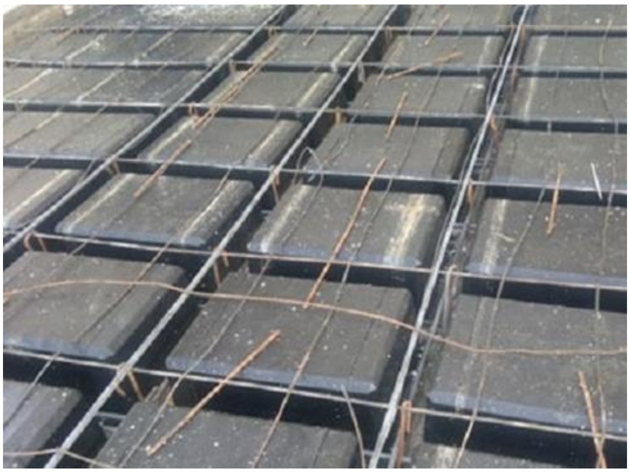


Figure 3.5. Contour deformations of waffle slab

4- Practical comparison

4-1- Simplified installation:

To install a waffle system, the fillers must be positioned then reinforcement performance is completed by special method. This process will require more time and accuracy compared to Contruss system installation. Meanwhile, required time for installation of both systems is approximately equal.




4-2- Variability of filler dimensions:

Waffle fillers are manufactured in the factory according to specified dimensions, and any variation in size in order to gain desired dimensions will be impossible. Whereas, the Contruss filler is capable to be manufactured with dimensions ranging from 45 to 60 cm, and 12 to 65 cm in height. Based on manufacturing in various dimensions as well as being economical, Contruss waffle fillers are capable of applying instead of one-way and two-way waffle slabs.

Figure 4.2. Various dimensions of contruss filler

4-3- Easy to be slashed:

By using of polystyrene, the Contruss filler can be slashed down easily by means of saw to fit the required spaces in correspondence of irregular scheme with various span length. This unique qualification will make it easy to position the fillers at the corner region on site.

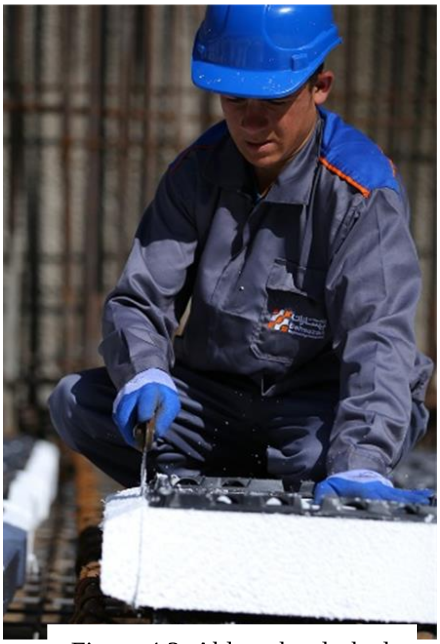


Figure 4.3. Able to be slashed

4-4- Providing appropriate clearance for rebar:

Based on the existence of trays placed over the fillers, rebar will be positioned in desired distance as clearance is provided suitably in the Contruss system, which makes it possible to design the steel mesh without restrictions.

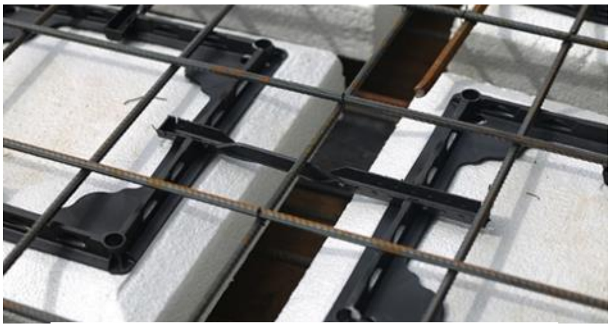


Figure 4.4. Appropriate clearance for rebar

4-5-Resistance subjected to noise and vibration:

Material strength in sound transmission is investigated in two segments: 1) airborne noise, 2) percussion noise.

In general, the concrete ceilings resist properly in transmission of airborne noise; as consequence, the Contruss slab operates suitably subjected to airborne noise, because of participating two concrete layers. In addition, by involving polystyrene, resistance of Contruss ceiling subjected to percussion noise will be increased, which implies superiority of Contruss system compared to waffle system.

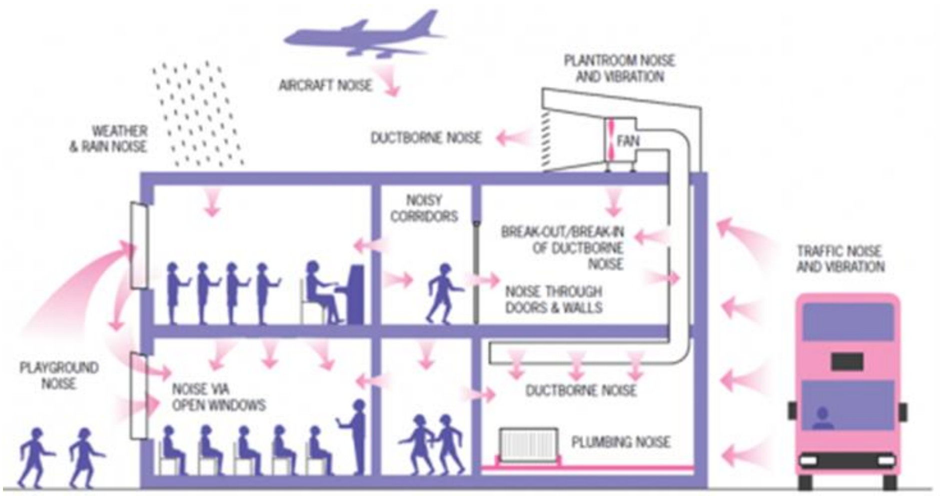


Figure 4.5. noise transmission in building

Moreover, with regard to the increased rigidity of Contruss voided slab, less ceiling vibration will be transferred in comparison with the common concrete slabs, that will be a relief for residents.

Figure 4.6. Transmission of vibration in building

4-6- Resistance subjected to fire:

Due to existence of two concrete layers and a non-flammable polystyrene between them, the Contruss ceiling will function properly in transmission of heat when subjected to fire, avoiding heat from transferring between floors. The Contruss filler has ignitability testing certificate by the road, housing and urban development research center.

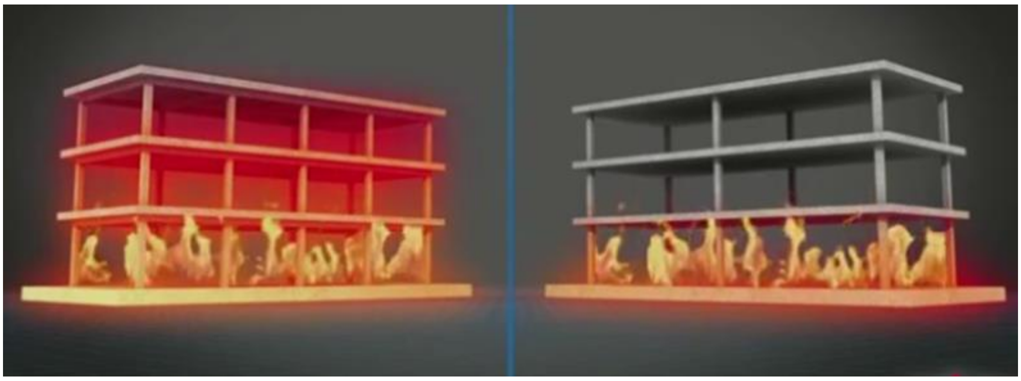


Figure 4.7. Non-transferring of heat between floors

The ignitability testing certificate of Contruss system:

Road, Housing and Urban Development Research Center

Fire engineering department

The conclusions of ignitability test on samples of flame retardant expanded polystyrene foam

Sample name: Contruss permanent filler core made of flame retardant expanded polystyrene foam	**Average thickness (mm):** 60.9	**Average density (kg/m³):** 6.4

Sampling method	Sent by the applicant
Description of sub-layer	Without sub-layer
Deviation of test procedure	-
Description point of applied flame	Edge flame
Duration of applied flame	According to the attachment A

Observations	**1- The ignition:** No **2- Reaching top of flame up to 150 mm over point of applied flame:** No **3- The ignition of filter paper:** No **4- Physical behavior of sample:** contracted, melted

Concluding:

- The sample is a flame retardant type.

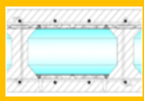
Road, Housing and Urban Development Research Center

#6-96-3519

5- Conclusions and final comparison table

- By including two concrete layers and shear webs, Contruss ceiling forms a high rigid slab that will create a rigid diaphragm subjected to lateral loads and also provide span up to 20-meters.
- Contruss system will represent a flat soffit with smooth bottom surface of ceiling, whereas waffle system will create an uneven bottom surface for ceiling. This difference will effect on useful height of floor, system installations and sub-constructing of the ceiling.
- Slab weight is a good factor implying optimization level of structure, from two aspects. First, it indicates amount of consuming concrete, so it will be an indicator of costs. Second, increase in slab weight will highly effect on gravity and lateral loads of elements. Therefore, creating voids in slab for reducing dead load will be so impressive. As illustrated in this report, Contruss system will do this task (creating voids in slab) more efficiently than waffle system.
- Ceiling height: slab thickness of Contruss system for spans beyond 7 meters will be less than waffle system. The reasons can be evaluated from two aspects. First, the Contruss system includes I-shaped ribs that will create higher moment of inertia compared to T-shaped ribs in waffle system, which is indicated in diagram 3. Second, unlike to the smooth bottom surface of slab in the Contruss system, the bottom surface of waffle slab will be hollow and pitted, which will require sub-construction as well as dropped ceiling installation, leads to increased total thickness of the ceiling.
- Cost: by considering the weight as a suitable criterion, Contruss slab will be more economical for spans beyond 7 meters, according to the diagram 2 because it weighs less than waffle system. Furthermore, requiring sub-constructing for waffle system will result in additional costs.
- Resistance subjected to noise and fire: The Contruss system provides more benefit in terms of functional specifications such as resistance in fire, vibration and noise transmission. Involving of two concrete layers in Contruss system will increase the strength of ceiling subjected to transmission of heat and noise. In addition, practicing of polystyrene in the Contruss filler has been contributed to providing more strength in sound transmission.

In the following table, the specifications of two systems are compared to each other:

	Contruss 	Waffle 
Adapt to large spans and cantilevers	★★★★★	★★★★½
Resistant in sound transmission	★★★★½	★★½
No need for dropped ceiling	★★★★½	½
Construction speed	★★★	★★★
Simplified implementation	★★★★½	★★★★
Lack of large soffit and drops	★★★★½	★
Fire resistance	★★★★★	★½
Construction costs for spans beneath 8-meters	★	★½
Construction costs for spans beyond 8-meters	★★★★★	★★★½
Reduced vibration and deflection	★★★★★	★★★
Reduced weight of structure	★½	★★★
No need for special parties to install	★★★★½	★★★★
Adapt to irregular large spans	★★★★★	★★★½
Adapt to irregular supports	★★★★★	★★★★½

Complete points: ★★★★★