COMPARISON OF ENERGY EFFICIENT COLD ROLLS STEEL CONSTRUCTION WITH THE PREVAILING CONVENTIONAL CONSTRUCTION

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Abstract

Cold-formed steel products find extensive application in modern construction in both low-rise and high-rise steel buildings. In low-rise construction, primary as well as secondary framing members are fabricated using cold-formed steel sections, while in high-rise buildings; roof and floor decks, steel joists, wall panels, door/window frames, and sandwich panel partitions are successfully built using cold-formed steel sections. In cold roll steel construction, fibre cement board is used as cladding material over steel sections on inside and outside, which creates a cavity wall action. Later on, glass wool and mineral wool insulation are also inserted in these walls making buildings more energy efficient in summer as well as in winter. In this paper, a comparison has been carried out between ordinary/conventional construction of a two roomed simple building and cold roll steel construction for the same type of building. The comparison includes design, analysis, structural detailing, cost and management on site for execution of both types of systems. It was found that cold roll steel construction has highest strength-to-weight ratio, easy to handle, quick and precise in manufacturing, fast in construction and dimensionally stable - does not expand or contract with moisture content. Also there is less probability of foundation problems due to less weight and less probability of damage due to earthquakes and heavy winds. Lighter structure with stronger connections results in less seismic forces. As cold roll steel construction is new in Pakistan and most of the material is being imported, so its prices are on higher side but still approximately 40%-50% less than conventional construction beside it's all other benefits and energy efficiency behaviour.

Keywords: Light gauge steel, energy efficient, management, cost, construction.

1. Introduction

Construction Technology involves study on methods of construction to successfully achieve the structural design with recommended specifications and conditions of contract. It also includes study of geotechnics, construction equipments, and temporary works like scaffolding, false work and formwork etc. required to facilitate the construction process conforming to health and safety regulations. Construction technology also includes study of latest erection and fabrication processes. The modern trend is towards constructing lighter and taller buildings which is always a big challenge in an era of financial crunch (Rondal & Dubina 2005). To achieve it successfully there is a need to have sophisticated equipments employed in the construction process. Excavation of foundation is also a challenging task in an area surrounded by existing buildings and a busy road. All of these factors should be considered while estimating the cost of the construction project. Construction technologists work very closely with construction managers and the quantity surveying professionals (Wei-wen Yu 2000).

After the devastating Kashmir earthquake in 2005, Pakistan has instituted strict building codes. The construction in Pakistan has been increased 30-50% due to implementation of new building code which requires strengthening of structures to withstand earthquake of 8 to 8.5 Richter scale magnitudes. As Pakistan is facing severe energy crisis and inflation in construction cost, there is an urgent need to bring new technologies that can accommodate these shortcomings in Pakistan; i.e. the construction should be earthquake resistant, cost effective and energy efficient. In earthquake affected areas of Pakistan, “Earthquake Reconstruction and Rehabilitation Agency (ERRA)” has practically introduced technologies like “Light Gauge Steel Structures”, “Structural Concrete Insulated Panels” and “Sandwich Panels”, but still these are restricted to earthquake areas on a small scale and are not being employed countrywide on a mass scale.

In this study, it is tried to put forward some results based on the comparison of reinforced cement concrete frame structures with light gauge steel structure. These results are focused on energy efficiency, design, analysis, structural detailing, cost, environmental considerations, and management on site for execution of both types of systems. Analysis and design of structures is done with the help of SAP 2000, while planning and scheduling of both types of buildings involves the use of Primavera P6. A unit scale check post type building consisting of two rooms and one veranda situated just above the fault line is selected for comparison with room sizes of $16^{/}$ x $22^{/}$ and $20^{/}$ x $16^{/}$ as well as veranda size of $20^{/}$ x $6^{/}$ having a total covered area of 869 ft^2. Bearing capacity of soil is taken as 0.75 tons/sft, Two construction techniques are applied on this unit scale building and results are taken for comparison.

2. Structural design & analysis

2.1 Design parameters

Following loads have been considered for computing the applicable forces acting on the structure (Anil & ChoprA 2005):

1- Dead Loads (self load, finish load)
2- Live Loads (taken from UBC97, chapter 16))
3- Earthquake loads (As per zone requirements i.e. Zone 4 parameters as laid down by UBC-97, explained in section 2.1.1)
4- Wind loads (parameters explained in section 2.1.2)
5- Snow load (taken as 30 psf)

2.1.1 Seismic parameters

The following seismic parameters are adopted in the structural design (UBC 97, ASCE 7-05):

Earthquake Zone = 4	Near source factors: Na = 1 & Nv = 1.2	
Importance factor = 1	R_w in X direction = 8.5	R_w in Z direction = 8.5
Soil profile type = S	Type = SD (stiff soil profile)	CT value = 0.03

2.1.2 Wind parameters

Following wind parameters are adopted in the structural design (IBC 2003, ASCE 7-05):

Wind zone = ASCE zone A	Importance factor (I) = 1
Topographical factor = 1	Basic wind speed = 100 miles/hour
Exposure category = C	Wind direction angle = 0
Windward coefficient Cp = 0.8	Leeward coefficient Cp = 0.5
Gust factor = 0.85	Directionality factor = 0.85
Type of structure = rigid	Building type = enclosed building

2.2 Design and analysis of RCC structure

SAP 2000 software was selected for design & analysis, which has been developed by "Computer System Incorporation (CSI), University of Berkeley, USA". Authenticity and credibility of the software has been tested and is accepted worldwide. The method on which design of this building was carried out is "Ultimate Stress Design (USD)". Structural adequacy of the building was maintained following the guidelines of ACI 318-02 (American Concrete Institute for Building Design) & UBC-97 (Uniform Building Code for Seismic Requirements). Strength requirements of ACI 318-02 have been used for load combinations and strength reduction factors (Andrew K 1998). Serviceability is measured by considering the magnitude of deflections, cracks and vibrations of structures as well as by considering the amount of surface deteriorations of the concrete and corrosion of the reinforcing steel (Elnashai 2001).

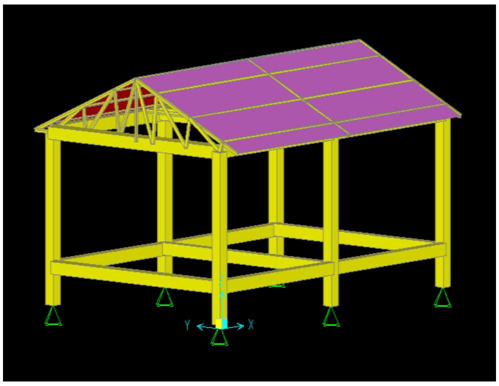

Figure 1: Geometry (RCC)

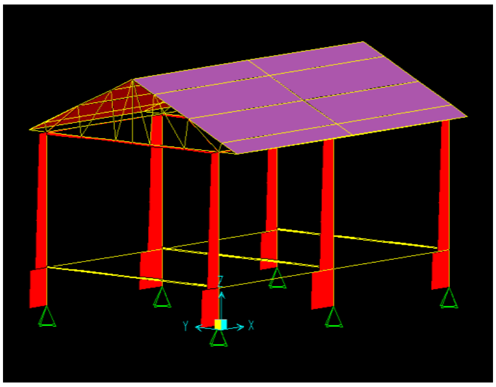

Figure 2: Axial force diagram (RCC)

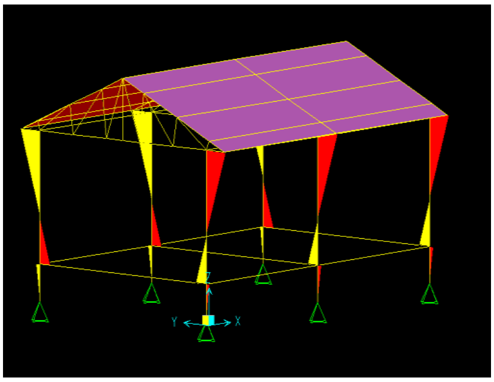

Figure 3: Bending moment diagram (RCC)

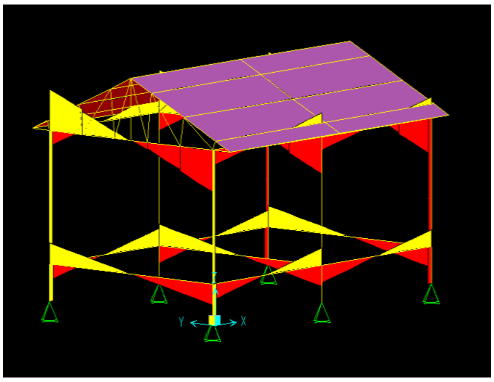

Figure 4: Shear force diagram (RCC)

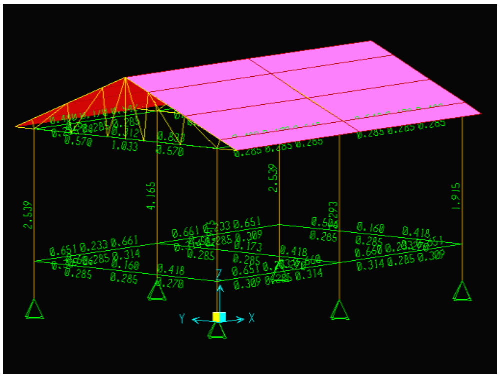

Figure 5: Design results (RCC)

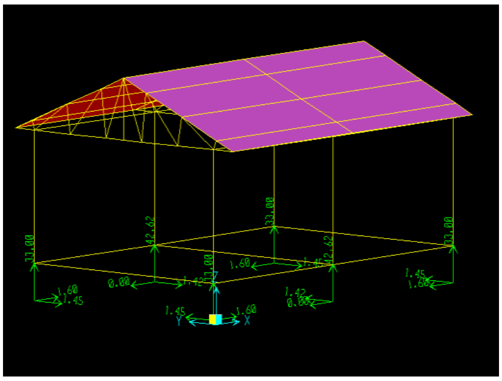

Figure 6: Joint reactions (RCC)

2.3 Design and analysis of Light Gauge Steel (LGS) structure

Again SAP 2000 software was selected here. The raft was designed by using SAFE software. Structural adequacy is maintained following the guidelines of the AISI-LRFD96 (American Iron and Steel Institute for Building Design) & UBC-97 (Uniform Building Code for Seismic Requirements). Strength requirements of AISI-LRFD 96 were used for load combinations and strength reduction factors (Hancock 2005).

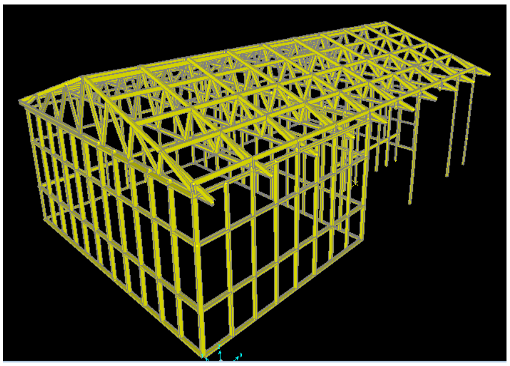

Figure 7: Geometry (LGS)

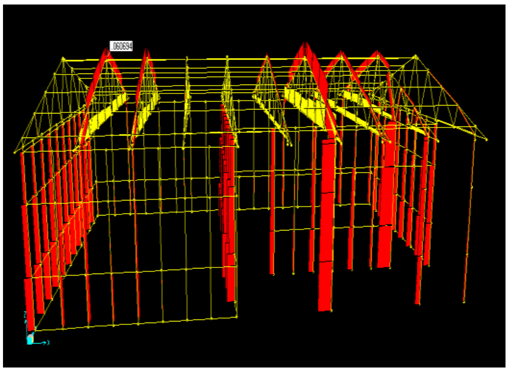

Figure 8: Axial force diagram (LGS)

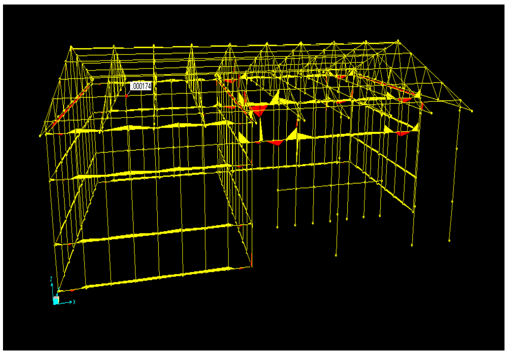

Figure 9: Bending moment diagram(LGS)

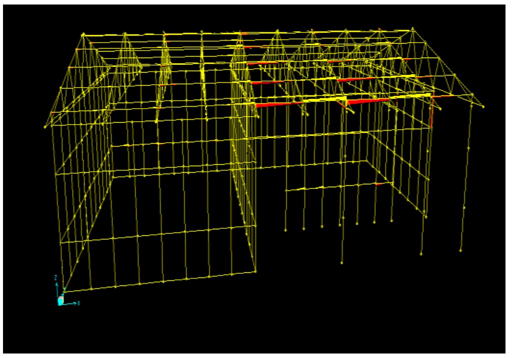

Figure 10: Shear force diagram (LGS)

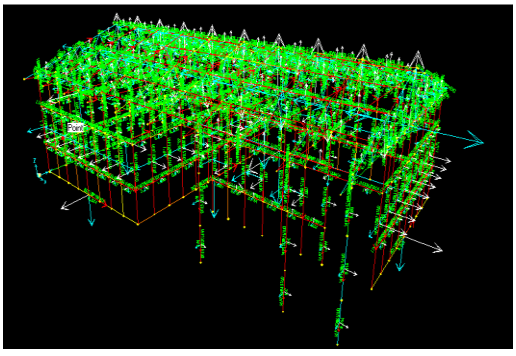

Figure 11: Design results (LGS)

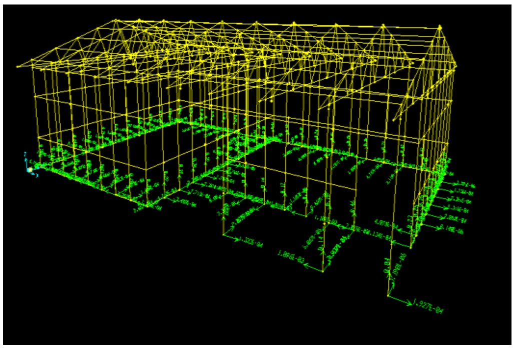

Figure 12: Joint reactions (LGS)

2.4 Comparison of design & analysis results

Table 1: Comparison of design & analysis results of "Conventional" & "LGS" structures.

Sr. no	*Comparison factor*	*Conventional structure (RCC)*		*Cold rolled steel structure (LGS)*	
1	*Beam sizes & Tracks*	*Plinth beams*	*$12^{//}$ x $18^{//}$*	*Bottom track*	*C90mm x 40mm x 75mm*
		Sill beam	*No sill beam*	*Sill track*	*C90mm x 40mm x 75mm*
		Lintel beams	*$9^{//}$ x $9^{//}$*	*Lintel track*	*C90mm x 40mm x 75mm*
		Roof beams	*$12^{//}$ x $15^{//}$*	*Roof track*	*C90mm x 40mm x 75mm*

2	*Columns & Studs*	*All columns are of same size*	*12″ x 12″*	*Cladding column*	*C90mm x 40mm x 75mm*
		------	------	*Box section*	*2 C90mm x 40mm x 75mm*
		------	------	*Corner studs*	*3 C90mm x 40mm x 75mm*
3	*Raft*	*Size*	*37′-9″ x 23′*	*Size*	*37′-9″ x 23′*
		Thickness	*12″*	*Thickness*	*5″*
4	*Truss*	*Spacing between trusses*	*Can be adjusted as required*	*Spacing between trusses*	*Shall not be more than 4′*
		No of trusses	*3*	*No of trusses*	*10*
		Material used	*Hot rolled angle sections as truss members and C-sections as purlins*	*Material used*	*Cold roll C-sections for both truss members and purlins*
		Total weight of truss	*1527 Kg*	*Total weight of truss*	*642 Kg*
5	*Expansion coefficient*	*Bricks*	*5.5 x 10^{-6} m/m K*	*Doesn't expand on heating and contract on cooling*	
		Concrete	*9.8 x 10^{-6} m/m K*		
6	*Weight on ground*	*145 Kg/ft^2*		*42.65 Kg/ft^2*	
7	*Anti seismic*	*More susceptible due to increased dead weight*		*Earthquake-proof.*	
8	*Anti wind*	*Not a governing factor in low rise buildings*		*Wind-proof performance: against 12 degree typhoon.*	
9	*Bracings in wall panels*	*No bracing required in wall panels*		*Bracing is required in all wall panels to prevent buckling of slender members*	
10	*Connections*	*No connections are required in whole structure as concrete is cast monolithically except in truss for jointing of hot rolled sections.*		*Wall panels and truss members are connected through bolts, screws, steel clips etc.*	

3. Cost estimation

An estimate of the cost of a construction job is its probable cost computed from plans and specifications. The cost estimates for two types of constructions are given in tables 2 & 3 respectively. The schedule of rates for RCC building is taken from "Pakistan Institute of Cost and Contracts (PICC)". Whereas unit cost for LGS structure is taken from "National Engineering Services Pakistan (NESPAK) Limited".

3.1 Summary of cost estimation for RCC construction

Table 2: Cost calculation of conventional RCC construction

Sr. no	Description of items	Units	Total quantity	Unit cost (PKR/unit)	Total cost (PKR)
1	Earth work excavation in ordinary soil as per design section, grade, lined and profiles manually, with shovel or any other tool and disposal up to single throw, dressing in specified manner, as per drawings and in accordance with the specifications.	cft	3690.76	2.73	10077
2	Backfilling with ordinary excavated soil within 30 m lead, laid in 20 cm thick layer including watering, ramping and compaction in required density, complete as per drawings and in accordance with the specifications.	cft	3097	2.52	7797
3	Providing and laying plain cement concrete of nominal mix ratio as 1:4:8, using aggregates of required properties including mixing, transporting, placing, compacting, finishing and curing etc, complete in all respects as specified but excluding the cost of form work.	cft	312.052	153.06	47763
4	Providing and laying 1st class solid Burnt brickwork in wall over 12″ thick laid and jointed in cement mortar 1:6 in foundation and plinth (up to 3 m depth) straight, including scaffolding raking out joints & curing complete as per specifications.	cft	233.625	229.2	53545
5	Providing and laying Ist class solid burnt brickwork in wall 9″ thick laid and jointed in cement mortar 1:4 in ground floor straight, including scaffolding raking out joints & curing complete as per specifications.	cft	998.5	229.2	228857
6	Providing and laying plain cement concrete of nominal mix ratio 1:2:4 as under layer, using aggregates of required properties including mixing, transporting, placing, compacting, finishing and curing etc., complete in all respects as specified but excluding the cost of form work .	cft	1861	178.56	332300
7	Providing and laying deformed (Grade-40) reinforcement bars including cost of straightening, cutting, bending, binding, wastage, and such overlaps as are not shown in the drawings, placing in position on cement concrete 1:2:4 precast spacer or M.S. chairs and tying with binding wire etc. complete in all respects as per drawings and in accordance with the specifications.	ton	4.324	106772	461684
8	Providing and applying 13 mm (1/2″) thick cement sand plaster (1:4) on walls and columns etc, including making edges, corners, and curing etc. complete in all respects as per drawings and in accordance with the specifications.	sft	3530.25	32	112968

9	*Providing, erecting, fixing and removing of steel form work with steel scaffolding including all required accessories, complete in all respects, as per drawings and specifications.*	*sft*	*1966*	*50*	*196600*
10	*Supply, erection and fixing of prefabricated structural steel of ASTM A-36 of grade 50 for truss angle sections*	*kg*	*251*	*110*	*27600*
11	*Purlins C-sections conforming to ASTM A36 of size 4″x7.25″.*	*kg*	*1276*	*110*	*143000*
12	*Supplying and fitting in position, 24 gauge CGI pre-painted sheets for roofing, include overlaps, limpets, washers, GI bolts, nuts etc complete in all respects, as shown on drawings*	*kg*	*680*	*110*	*74850*
13	*Gusset plate 3/8″ thick*	*kg*	*14.83*	*110*	*1632*
14	*J-Bolts conforming to ASTM-325 Zinc coated*	*No*	*30*	*50*	*1500*
15	*Anchor bolts conforming to ASTM-325 Zinc coated*	*No*	*786*	*50*	*39300*
	Total			*17,39473*	

Total cost of RCC building = *17, 39473 PKR*
Cost per square foot for RCC construction = *2000 PKR/ft^2*

3.2 Summary of cost estimation for cold roll steel (LGS) construction

Table 3: Cost calculation of cold roll steel (LGS) construction

Sr. no	*Description of items*	*Units*	*Total quantity*	*Unit cost (PKR/unit)*	*Total cost (PKR)*
1	*Earth work excavation in ordinary soil as per design section, grade, lined and profiles manually, with shovel or any other tool and disposal up to single throw, dressing in specified manner, as per drawings and in accordance with the specifications.*	*cft*	*2691*	*2.73*	*7350*
2	*Providing and laying plain cement concrete of nominal mix ratio as 1:4:8, using aggregates of required properties including mixing, transporting, placing, compacting, finishing and curing etc, complete in all respects as specified but excluding the cost of form work.*	*cft*	*206*	*153.06*	*31531*
3	*Providing and laying plain cement concrete of nominal mix ratio 1:2:4 as under layer, using aggregates of required properties including mixing, transporting, placing, compacting, finishing and curing etc., complete in all*	*cft*	*532.5*	*178.56*	*95084*

	respects as specified but excluding the cost of form work .				
4	*Providing and laying deformed (Grade-40) reinforcement bars including the cost of straightening, cutting, bending, binding, wastage, and such overlaps as are not shown in the drawings, placing in position on cement concrete 1:2:4 precast spacer or M.S. chairs and tying with binding wire etc. complete in all respects as per drawings and in accordance with the specifications*	*tons*	*1.305*	*106772*	*139338*
5	*Supply, erection and fixing of prefabricated structural steel of ASTM A653 of grade 50*	*kgs*	*1570*	*125*	*1,96250*
6	*Providing and fixing in position insulation with maximum thermal conductivity of 0.04 W/m k in wall panels and under roofing sheets.*				
6a)	*Mineral wool with vapour barrier 50 mm thick in walls*	*sft*	*1340*	*45*	*60,300*
6b)	*Glass wool 50 mm thick supported by* $14^{//}$ *gauge wires placed at* $6^{//}$ *c/c with vapour barrier, under roofing sheets etc*	*sft*	*792*	*45*	*35,640*
7	*Providing and fixing 12 mm thick non-asbestos fiber cement boards conforming to ASTM C-1186 to be provided on outer sides of wall panels including water tight self drilling screws and joint sealing etc. complete in all respects.*	*sft*	*2950*	*14*	*41,300*
8	*Supplying and fitting in position, 24 gauge CGI pre-painted sheets for roofing, include overlaps, limpets, washers, GI Bolts, nuts etc complete in all respects, as shown on drawings*	*kg*	*680*	*110*	*74850*
9	*J Bolts*	*No*	*120*	*50t*	*6000*
10	*Self drilling screws*	*No*	*4963*	*1.65*	*8189*
11	*Anchor Bolts*	*No*	*132*	*50*	*6600*
12	*Clips*	*kg*	*77*	*110*	*8470*
	Total				*7,10902*

Total cost of cold formed structural steel building = 7,10902 PKR

Cost per square foot for cold roll construction = 820 PKR/ft^2

3.3 Comparison of cost estimates

Table 4: Cost/sft comparison of RCC and LGS constructions

Conventional building	*Cold roll steel building*
2000 PKR/ft^2	*820* PKR/ft^2

4. Planning and scheduling

Primavera Project Planner 6.0 was used for planning & scheduling of both types of structures. The construction work involved in both types of structures was divided into different activities. Durations of activities were assumed/calculated after assigning available resources at the site. Project starting date was selected as 20 January 2012. Critical paths were found and floats were calculated. Typical WBS's of both types of structures were taken as print out of P6 and given in figures 3 & 4 respectively.

RCC — Classic WBS Layout

Activity ID	Activity Name	Original Duration	Planned Start	Planned Finish	Total Float
RCC		66	20-Jun-12	04-Sep-12	0
START OFTHE PROJECT		0	20-Jun-12	20-Jun-12	0
ST00	START OFTHE PROJECT	0	20-Jun-12		0
STRUCTURE WORKS		56	20-Jun-12	23-Aug-12	2
SUBSTRUCTURE		18	20-Jun-12	10-Jul-12	0
Raft Foundation		7	20-Jun-12	27-Jun-12	0
RF01	CONCRETING	1	26-Jun-12	26-Jun-12	0
RF02	CURING	1	27-Jun-12	27-Jun-12	0
RF03	EXCAVATION	2	20-Jun-12	21-Jun-12	0
RF04	LEAN CONCRETE	1	22-Jun-12	22-Jun-12	0
RF05	FORMWORK AND STEEL FIXING	2	23-Jun-12	25-Jun-12	0
COLOUMNS UPTO PLINTH		6	28-Jun-12	04-Jul-12	0
PC06	FORMWORK,STEEL FIXING,CONCRETING	6	28-Jun-12	04-Jul-12	0
PLINTH BEAM		5	05-Jul-12	10-Jul-12	0
PB07	FORMWORK AND STEEL FIXING CONCRE	5	05-Jul-12	10-Jul-12	0
SUPER-STRUCTURE		33	17-Jul-12	23-Aug-12	2
LINTEL BEAM		2	22-Aug-12	23-Aug-12	2
LB08	FROMWORK,STEEL FIXING,CONCRETING	2	22-Aug-12	23-Aug-12	2
COLOUMNS TILL ROOF		7	17-Jul-12	24-Jul-12	0
RC09	FROMWORK,STEEL FIXING,CONCRETING	7	17-Jul-12	24-Jul-12	0
ROOF BEAM		6	25-Jul-12	31-Jul-12	0
RB10	FORMWORK,STEEL FIXING,CONRETING A	6	25-Jul-12	31-Jul-12	0
ROOF		10	01-Aug-12	11-Aug-12	0
ARCHITECTURAL WORKS		48	11-Jul-12	04-Sep-12	0
SUB-STRUCTURE		5	11-Jul-12	16-Jul-12	0
EARTH WORKS		2	14-Jul-12	16-Jul-12	0
EW11	BACK FILLINGAND COMPACTION UNDER	2	14-Jul-12	16-Jul-12	0
BRICK MASONRY WORKS		3	11-Jul-12	13-Jul-12	0
BWSBST12	BRICK MASONRY WORKS IN FOUNDATIOI	3	11-Jul-12	13-Jul-12	0
SUPER-STRUCTURE		20	13-Aug-12	04-Sep-12	0
BRICK MASONRY WORKS		12	13-Aug-12	25-Aug-12	0
BWSPST13	BRICK MASONRY IN SUPER-STRUCTURE	12	13-Aug-12	25-Aug-12	0
CEMENT PLASTER		8	27-Aug-12	04-Sep-12	0

Figure 13: WBS of RCC construction

LGS — Classic WBS Layout

Activity ID	Activity Name	Original Duration	Planned Start	Planned Finish	Total Float
LGS		16	20-Jun-12	07-Jul-12	0
START OF THE PROJECT		0	20-Jun-12	20-Jun-12	0
ST00	START OF THE PROJECT	0	20-Jun-12		0
STRUCTURE WORKS		11	20-Jun-12	02-Jul-12	0
SUB STRUCTURE		6	20-Jun-12	26-Jun-12	0
RAFT FOUNDATION		6	20-Jun-12	26-Jun-12	0
RF01	EXCAVATION	1	20-Jun-12	20-Jun-12	0
RF02	LEAN CONCRETE	1	20-Jun-12	21-Jun-12	0
RF03	FORMWORK AND STEEL FIXING	2	21-Jun-12	23-Jun-12	0
RF04	CONCRETING	1	23-Jun-12	25-Jun-12	0
RF05	CURING	1	25-Jun-12	26-Jun-12	0
SUPER STRUCTURE		5	26-Jun-12	02-Jul-12	0
SS06	ASSEMBLING AND ERECTION OF WALL PA	2	26-Jun-12	28-Jun-12	0
SS07	ASSEMBLING AND ERECTION OF TRUSS I	3	28-Jun-12	02-Jul-12	0
ARCHITECTURAL WORKS		5	02-Jul-12	07-Jul-12	0
CALDDING AND FALSE CEILING		5	02-Jul-12	07-Jul-12	0
CFS08	FIXING OF CALDDING	3	04-Jul-12	07-Jul-12	0
CFS09	PROVIDING OF INSULATION	2	02-Jul-12	04-Jul-12	0
END OF THE PROJECT		0	07-Jul-12	07-Jul-12	0
END10	HANDING OVER AND INAUGURATION	0		07-Jul-12	0

Figure 14: WBS of LGS construction

Table 5: Comparison of durations of RCC and LGS constructions

Duration of conventional construction without finishes	*Duration of cold roll construction without finishes*
66 days	*16 days*

5. Energy efficiency

Table 6: Comparison of Energy Efficiency of RCC and LGS Constructions

Sr. no	*Comparison factor*	*Conventional construction*		*Cold roll construction*	
1	*Carbon emission during demolishing*	*80%-88% embodied carbon emission*		*Negligible amount of carbon emission about 0.005 Kg/ft^2*	
2	*Thermal conductivity*	*Bricks*	*1.6 W/m^2.K*	*Glass wool and mineral wool*	*0.04 W/m^2.K*

6. Environmental considerations

Table 7: Comparison of environmental considerations of RCC and LGS constructions

Sr. no	*Comparison factor*	*Conventional construction*		*Cold roll construction*	
1	*Recycling*	*Recycled content*	*0%*	*Recycled content*	*60%*
		End of life time recycling rate	*50%*	*End of life time recycling rate*	*98%*
2	*Noise pollution*	*No preventive measures*		*Sensitive to the audio frequency ranging 250-1000 Hz*	

7. Conclusions

- The depth of raft footing i.e., 5$^{//}$ is too economical for LGS construction as compared to raft depth for conventional construction i.e., 12$^{//}$.
- Unit weight of cold roll structure is 42.65 Kg/ft^2, while unit weight for RCC structure came out to be 145 Kg/ft^2. Thus LGS structure is proved to be more lightweight as compared to conventional RCC structures resulting in less foundation problems as well as less probability of damage due to earthquakes and heavy winds.
- Cold roll construction is proved to be 2.45 times cheaper than conventional construction.
- Cold-roll technology takes 16 days for completion of frame structure while conventional method consumes 66 days for the same structure. Hence Cold-roll technology is proved to be 4 times faster than conventional construction.
- Cold roll structural steel is 98% recyclable and has 60% industry recycling rate while conventional construction is 50% recyclable and has 0% industry recycling rate.
- Cold roll construction is noise absorbent and control noise pollution while conventional construction has no such preventive measures.

- Cold-roll has stronger connections resulting in less seismic forces whereas in conventional concrete, seismic forces are dominant.
- Cold-roll has insulation, between the fiber cement board cladding, of mineral wool and glass wool in its panels, which makes it energy efficient; whereas no such system of insulation is provided with the conventional concrete.

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