THIN WALL REINFORCED CONCRETE AS LOW COST SUSTAINABLE ALTERNATIVE FOR SINGLE FAMILY HOUSES IN PAKISTAN

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ABSTRACT
As per the statistics of the Pakistan Government, approximately 1/4th of the country's population is living in single room house. Natural calamities like floods and earthquakes also leave thousands homeless. There is an urgent need of research to device low cost construction techniques and develop cheap materials in order to make available inexpensive housing to common people. The main purpose of this study was to explore potential of ferrocement panels for quick construction in order to achieve economical housing in the country. To fulfil the said objective, eighteen ferrocement panels reinforced with galvanized iron mesh were tested in compression and flexure. Cost comparison of ferrocement panels with traditional brick construction was also carried out for a small unit of 65 m^2 (three marla) area. The results of testing demonstrate that ferrocement panels are capable to take care the expected loading in a single story house. Their high ductility and energy absorption make them favourable for the areas which are prone to seismic activity. The material cost of ferrocement panel construction is close to the conventional brick and mortar construction, however, a ferrocement panel house can be ready for living in almost 1/4th of the time as compared to its brick counterpart.

Keywords: Low cost housing; thin wall concrete; ferrocement

INTRODUCTION
Cost of constructing new houses is increasing rapidly throughout the world, therefore, building new houses has become very challenging for low income families. In the wake of rapidly growing population, need of affordable housing has become a much discussed and researched topic. Owning a dwelling is not an affordable proposition for a major section of the society (Sumadi and Ramli 2008). According to the data of Pakistan Government (2011) almost 1/4th of the total population in Pakistan is living in a single room housing unit. Natural disasters make the situation even worse and leave hundreds of thousands of people homeless and for these displaced people the principal need is to have a safe place to live.

Economical housing is a comparative term, which does not mean achieving low cost through reduction in quality (Tam 2011) or compromise on function. Instead, low cost is achieved through alternative construction techniques, light-weight materials, better resource management of resources etc. According to Miles (2003), housing is considers low cost if it can be acquired for up to 30% of the house hold income.

Cost of housing can be achieved either by using locally available low cost materials or by reducing time of construction through accelerated/innovative construction techniques. Pre-engineered steel structure is one such option, however this is more common for industrial buildings. Using steel prefabrication for housing may not be appropriate due to high initial cost and low serviceability attributes. On similar lines, some kind of cementitious material may be a better choice to carry out prefabricated house construction. Ferrocement is a material which has great potential to be used in cheap housing. Thin wall ferrocement panels can be easily manufactured in plants using common materials in a very short time and be assembled quickly in to a housing unit. Ferrocement is a thin wall concrete reinforced with layers of wire mesh, which are embedded in cement sand mortar (ACI 549R-97). In comparison to conventional concrete, the tensile strength to self-weight ratio of ferrocement is greater and it also has improved cracking behaviour. These are the reasons which make ferrocement a favourable material for water-tight and light-weight structures. Ferrocement is a very suitable alternative material for the construction of prefabricated houses. Non structural application of ferrocement like plant pots, chairs, tables and boats are being constructed since 1884 (Aboul-Anen et al. 2009).

The ductile behaviour of ferrocement is attributed to close distribution of reinforcement in the form of mesh. Ferrocement has great potential to become an economical choice for the construction of temporary as well as permanent structures (Saleem and Ashraf 2008). Use of ferrocement as a roofing material in less privileged communities has been previously reported by Ibrahim in 2011. Ferrocement has potential to be used to construct almost all kinds of structures which can be constructed using traditional materials and this is one of its major advantages. Although there are some limitation of ferrocement, however, within the limitation it be considered as one of the most suitable composite construction materials.

One of the primary reasons of selecting ferrocement for this project is that all its ingredients are coming available in Pakistan at a very reasonable price. The ferrocement panels are easy to manufacture, light weight, easy to transport and assemble which make them a very suitable choice for low cost prefabricated houses. The concept of assembling ferrocement housing unit has been previously proposed as a do-it-yourself concept by Saleem and Ashraf (2008).

The main purpose of the current research was to explore the viability of ferrocement panels as a substitute material for the construction of cheap housing units. An effort was made to reach an economical and structurally suitable design of section of the panel in terms of dimension and number of layers of wire mesh. A minor objective was to carry out comparison of cost between the traditional brick and mortar construction and the ferrocement construction.

EXPERIMENTAL WORK

Table 1 provides the test matrix which was developed to achieve the desired objectives of the research. A total of nineteen ferrocement panels were tested including one trial specimen. Size of each panel was 450mm x 1500mm. Number of galvanized iron (GI) mesh layers in each panel and the thickness of panels were varied, as presented in Table 1. Every panel had its own ID number which had information about the No. of mesh layers, thickness of panel and mode testing; flexure or compression. For instance, 30-2-F1 means that the panel is 30 mm thick with 2 mesh layers, it will be tested in flexure and it specimen 1 of such nature. For the specimen tested in axial, ‘F’ was replaced with ‘A’. Two specimens with each unique specification were tested.

Table 1 Test Matrix

No.	Panel ID	Reinforcement	
		Mesh Layers	Volume Fraction
1	30-2-F1	2	1.67
2	30-2-F2	2	1.67
3	30-3-F1	3	2.51
4	30-3-F2	3	2.51
5	40-3-F1	3	1.88
6	40-3-F2	3	1.88
7	40-4-F1	4	2.51
8	40-4-F2	4	2.51
9	50-4-F1	4	2.01
10	50-4-F2	4	2.01
11	50-5-F1	5	2.51
12	50-5-F2	5	2.51
13	30-2-A1	2	1.67
14	30-2-A2	2	1.67
15	40-3-A1	3	1.88
16	40-3-A2	3	1.88
17	50-4-A1	4	2.01
18	50-4-A2	4	2.01

Mortar for the ferrocement panels was prepared using ordinary portland cement which was acquired afresh for every batch of casting. Also, for consistency, cement from same source was used for the entire stock of specimens. Fine aggregates were used as per the recommendation of ACI 549 which recommends using sand which passes through sieve #8 (2.36 mm). Use of only small size aggregate is necessary because of thin section of panels and small opening size of mesh reinforcement. Sand from lawrancepur was used, which is considered one the best in Pakistan. Cement/sand ratio was kept as 1:2. This rich mix results in a dense matrix which in turns provides good compressive strength. The water to cement ratio varied between 0.4 and 0.43. Ferrocement can be prepared by using several types of reinforcement including chicken wire mesh, one dimensional fiber mats and discrete fibers etc. For this project, galvanized iron chicken mesh having square openings was selected, since it is locally available in abundance at a very cheap price. The opening size of the square mesh was 12.5 mm with a 1.4 mm diameter of wire. The volume fraction of reinforcement was varied by using different number of mesh layers from two to five. The ACI 549 allows using skeletal steel which keeps the wire mesh at correct spacing and position during the casting. Therefore, 6 mm diameter steel rebars were used as skeletal steel, which is the highest size allowed by ACI 549.

In order to achieve smooth finish, plywood was used in the formwork to cast the specimens. Three separate formworks were prepared for casting 30, 40, and 50 mm thick panels. Fresh mortar was prepared for casting each specimen. A pan type mixer was used to prepare the mortar. First of all dry mixing of the materials was carried out for 2 to 3 minutes and then water was added while the mixer was running. Wet mixing took another three minutes which ensured a uniform mix. The formwork was put on the flat table vibrator and the first, layer of mortar was placed, which would serve as clear cover for the wire mesh. It was then vibrated. On this first mortar layer, the wire mesh was positioned along with the skeletal steel on top of it. Then next mortar layer was then poured, which was followed by the next layer of wire mesh. In this manner, the specimens with the desired number of mesh layers were prepared. The final layer of mortar was placed on the top and was levelled with the help of a float to achieve a smooth finish. The panels were then transported to the curing room. After 48 hours of casting, the formwork was disassembled and the curing was carried out for four weeks with the soaked jute cloth.

Specimens tested in flexure were applied with two-point loading as presented in Figure 1. The spacing between the loads, and between loads and supports was kept as 1/3rd of the center-to-center span of the panel, which turns out to be 450 mm. A 75 mm clear distance was provided from the edge of the panel to the center of the support. A high speed data acquisition system was used to record the load and mid-span deflection at a sampling rate of 1 *hz*. Test was carried out by applying displacement at the rate of 0.5 mm per min. A pair of all the unique specimens was also tested in compression (see Fig. 2). For the axial case, a displacement transducer was positioned at the middle height to acquire the horizontal deflection. Compression test was run displacement control having the displacement rate of 0.5mm per min.

Fig. 1 Test Setup for Flexural Test

Fig. 2 Test Setup for Compression Test

As a criterion for acceptance, the expected bending moment and compressive load was calculated for a 5 m x 5m single story unit. The bending moment was based on the wind forces produced due to a wind velocity of 160 km per hr. The factored moment comes out to be 0.1 kN-m. The compressive load due to roof and snow comes out to be 121 kN for the most heavily loaded wall.

DISCUSSION ON RESULTS

Strength of Mortar in Compression

To determine the strength in compression, 100 mm dia. and 200 mm high cylinders were prepared from every batch. These cylinders were tested on 7th, 14th, and 28th day. Table 2 provides the summary of 28 days compressive strength of these cylinders. The maximum and minimum cylinder strength attained was 49.7 and 33.1 MPa, respectively. The average compressive strength of all eighteen batched was 41.6 MPa having a standard deviation of 5.0.

Flexural Tests

The Fig. 3 present the load-deflection response for the all the specimens. The specimens 50-5-F1 and 50-5-F2 achieved the ultimate loads of 8.17 and 5.9 kN, and max. deflection of 30.7 and 30.8 mm, respectively. The specimens 50-4-F1 and 50-4-F2 exhibited very similar responses in terms of ultimate loads, maximum deflection and stiffness. The ultimate load for both the specimens was nearly 16.5 kN. The failure mode of 50-5 F1,2 specimens was however more ductile than the specimens 50-4-F1,2.

The 40 mm thick specimens exhibited consistent trend of increase in ultimate loads with the increase of GI wire mesh. The specimens 40-4-F1 and 40-4-F2 attained the ultimate loads of 7.85 and 12.84 kN, and max. displacement of 38.6 & 42.2 mm, respectively. The specimens 40-3-F1 and 40-3-F2 reached max. displacement of 36.9 mm & 16.6 mm, respectively.

The wall panel with 30 mm thickness gained higher deflections in comparison with 40mm & 50mm thick specimens. However, their failure loads were smaller. The maximum deflection achieved by specimen 30-3-F1 was around 81 mm. For a constant volume fraction the ultimate load increases as the thickness of panel increases. The max. deflection, however, goes up with the reduction in the panel thickness.

Table 2 Compressive Strength at 28 Days

S. No.	Panel ID	28 Days Compressive Strength (Mpa)
1	50-5-F1	42.6
2	50-5-F2	44.7
3	50-4-F1	40.9
4	50-4-F2	37.1
5	40-4-F1	47.1
6	40-4-F2	39.1
7	40-3-F1	35.1
8	40-3-F2	47.2
9	30-3-F1	44.1
10	30-3-F2	43.1
11	30-2-F1	33.1
12	30-2-F2	48.1
13	50-4-A1	38.3
14	50-4-A2	42.1
15	40-3-A1	38.1
16	40-3-A2	49.7
17	30-2-A1	33.1
18	30-2-A2	43.1

The flexural cracks in all the specimens initially appeared in the mid-span region and then propagated towards the top with the increase in the crack width. As the applied load increased, more cracks started appearing in the region of constant bending moment. The appearance of cracks continued till the specimen failed. A typical pattern of the flexural cracks is shown in Figure 4.

Compression Tests

Figure 5 presents the load displacement responses for the compression tests. The slenderness ratio of the panels with 30, 40 and 50 mm thickness was 173, 130 and 104, respectively. The ultimate capacity and the vertical displacement at collapse increased as the panel thickness increased. The ultimate loads for specimens 30-2-A2, 40-3-A2, and 50-4-A1 were 284, 494 and 666 kN, respectively. The specimens with 30 mm thickness finally buckled at failure, while the panels with 40 and 50 mm thickness exhibited compression failure close to the support area.

First Crack and Ultimate Load

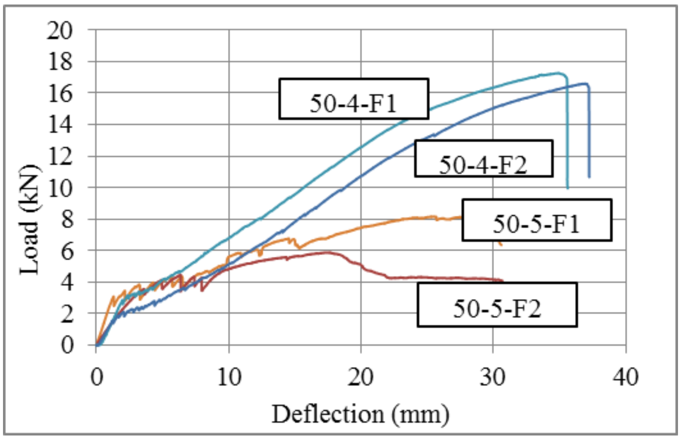
An increasing trend was observed in the magnitude of first crack load with the increase in the number of mesh layers and thickness of the panel. A comparison of first crack loads of twelve flexural specimens is presented in Figure 6. The ultimate load also followed a trend similar to the first crack load except the 50-5-F1,2 specimens. In the compression tests, ultimate loads increased with the increase in the panel thickness and number of mesh layers.

Energy absorption

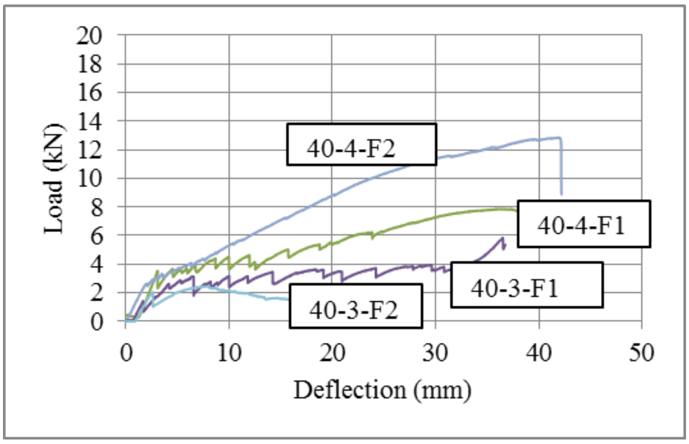
The area under the load deflection responses was calculated and reported as energy absorbed by the specimens. The specimens with 30 and 40 mm thickness exhibited increasing trend of energy absorption with the increase in numbers of mesh layers, however the 50 mm specimens showed in consistent behaviour (see Figure 7)

COST ANALYSIS

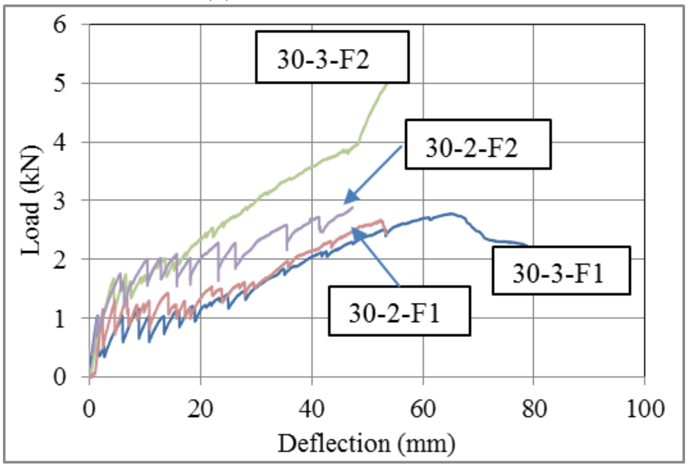
Material cost and labour cost are two main contributors towards the final cost of the housing unit. If a 50 mm thick wall panels with 5 layers of GI wire mesh are used to construct a house, its material cost is almost same as the conventional brick and mortar house. This comparison was carried out for a single family, single storey house having an area of 65 m^2 (3 Marlas). Table 3 provides a comparison of man hours break-up for the two types of construction. It is evident from this comparison that a prefabricated ferrocement house can be constructed in almost 1/4th of the time as compared to the traditional brick and mortar house. The reduction in the man hours requirement is the major contributor towards cost saving.



(a) 50 mm Thick Panel



(b) 40 mm Thick Panel



(c) 30 mm Thick Panel

Fig. 3 Load Deflection Reponses for Flexural Tests

SUMMARY AND CONCLUSION

The ferrocement wall panels proved to have sufficient strength to take care of the loading expected in a single family house. For a single story house the most heavily loaded wall of a 5m x 5m room has to bear an ultimate compressive load of 121 kN, which is just 42% of the minimum compressive collapse load of 284 kN, achieved by 30 mm thick panel. The highest compressive load among all panels was 666 kN, achieved by the 50 mm thick panel. For the wind velocity of 160 km/hr. the flexural demand for the panel comes out to be 0.1 kN-m which is much lower than the lowest achieved moment capacity of 0.6 kN-m for the 30 mm thick panel. The absolute maximum moment capacity was attained by 50 mm thick panel which amounts 3.88 kN-m. The entire stock of panels fulfils the moment requirement, however it is suggested to use at least 40 mm thick panel because the 30 mm thick panels fail in buckling unlike the 40 and 50 mm thick panels which fail in compression.

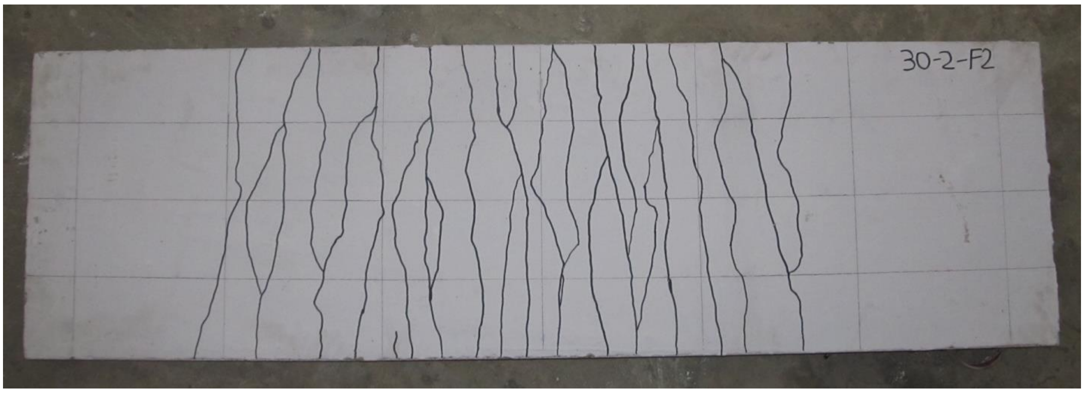


Fig. 4 Flexural Cracks in Specimen 30-2-F2

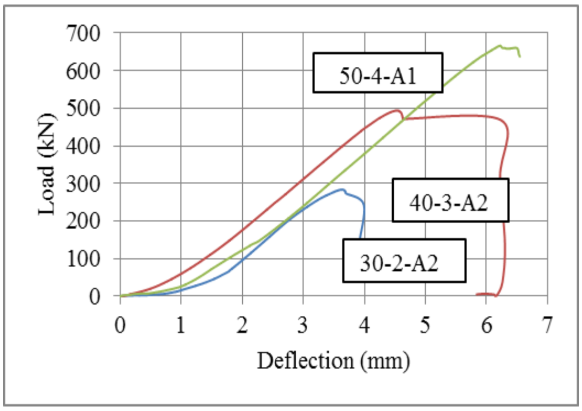


Fig. 5: Load Deflection Responses for Axial Load Tests

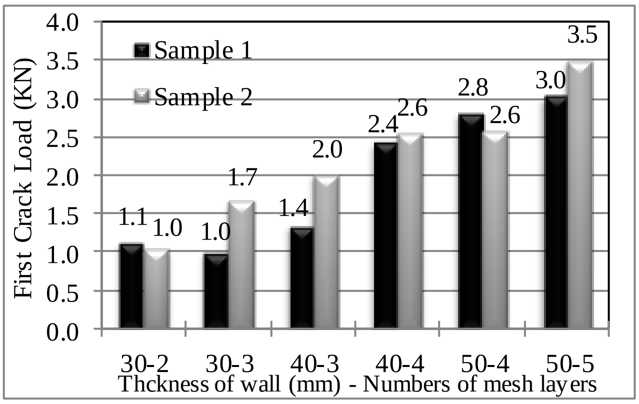


Fig. 6: First Crack Comparison for Flexural Test

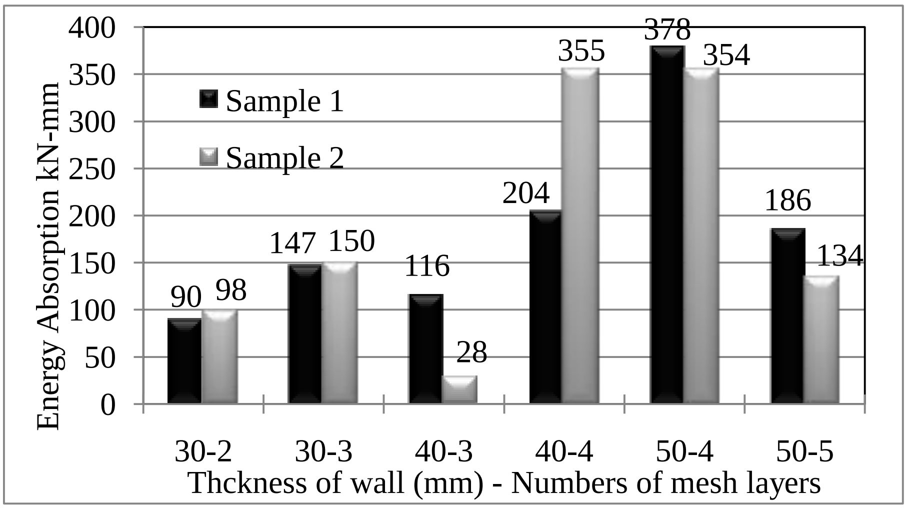


Fig. 7: Energy Absorption for the Flexural Tests

The material cost of 50 mm thick wall panel is similar to 230 mm thick wall made of traditional burnt clay bricks. The real saving in cost comes from the man hours. Only 1/4th time is required to assemble a ferrocement cement house as compared to the brick and mortar house.

Ferrocement panels have shown great promise to be used in house construction, however, work is still needed to evaluate their performance under impact loading and punching shear. Reinforcement meshes made of other non-corrosive materials like polypropylene may be used to develop corrosion free panels, which will be suitable for areas with high humidity. A scaled room made of ferrocement panels may be tested on shake table to prove their effectiveness in the earthquake prone areas.

Table 3 Breakup of Man Hours

No.	Activity	Brick Construction		Ferrocement Construction	
		Days	Man Hours	Days	Man Hours
1	Excavation/Back Filling	3	96	3	96
2	Strip Foundation	5	120	-	-
3	Block Foundation	-	-	1	24
4	Damp Proffing	1	24	-	-
5	Joint Sealing	-	-	1	16
6	Brick Wall	10	400	-	-
7	Ferrocement Panels Erection	-	-	2	48
8	Roof Shuttering	3	120	-	-
9	Concreting	1	80	-	-
10	Curing of Roof slab	14	-	-	-
11	Formwork removal	2	48	-	-
12	Wooden Truss Installation	-	-	1	24
13	Roof Sheeting Installation	-	-	1	24
	Total	**39**	**888**	**9**	**232**

REFERENCES

Aboul-Anen, B; El-shafey, A. & El-Shami, M. 2009. Experimentral and analytical model of ferrocement slabs. *International Journal of Recent Trends in Engineering* 1(6): 25-29.
ACI 549R-97. 1997. State-of-the-Art report on ferrocement. American Concrete Institute. Farmington Hills, MI.
Government of Pakistan, 2011. *Pakistan social and living standards measurement survey.* Government of Pakistan Statistics Division Federal Bureau of Statistics. Islamabad.
Ibrahim, H. M. 2011. Shear Capacity of Ferrocement plates in Flexure. *Engineering Structures.* 33(5): 1680-1686.
Miles, ME. 2013. Real estate development, principles and processes. 4th ed. Urban Land Institute. Washington D.C.
Saleem, MA & Ashraf, M. 2008. Low Cost Earthquake Resistant Ferrocement Small House. *Pakistan Journal of Engineering and Applied Sciences.* 2(1): 59-64.
Sumadi, SR & Ramli, M. 2008. Development of lightweight ferrocement sandwich panels for modular housing and industrialized building system. Universiti Teknologi Malasia.
Tam, VW. 2011. Cost Effectiveness of using low cost housing technologies in construction. *Procedia Engineering.* 14(2011): 156-160.