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COLD FORMED STANDARD STEEL PRODUCTS IN A
LOW COST HOUSE CONSTRUCTION METHOD

by

Robert W. Dannemann*

1) INTRODUCTION

The expansion of the world's population means a constant increase in the demand for more and better houses. In past decades, modern technology has brought important advances into many fields, but house construction is still employing conservative methods throughout the world. These methods can no longer keep pace with the demands for quantity and quality.

The low cost house construction system presented in this paper is based mainly on the use of standard cold formed steel components. This system can provide advantages and a broad field of possibilities for the people in developing countries.

2) SELECTION OF SYSTEM

2.1 Handling and Transportation

There exists a variety of industrial approaches for prefabrication that range from very sophisticated, completely factory assembled houses, or wall and deck panels, to "open systems", i.e., houses that are delivered in packages of modular components to be erected on the site.

It will be an interesting task to determine the system most suited for underdeveloped and developing countries with their constantly increasing populations and their need for accessible solutions.

Normally these countries are not located near the industrialized regions. That is why, apart from a low initial cost, shipping costs are a very important consideration. The cost of handling and transportation is of prior importance when job sites are located inland where access is difficult.

More elaborate systems, such as completely assembled houses or panels, have been designed to reduce labor in the field. In many places, this is an advantage, but all these systems may not be flexible enough to adapt to local conditions, such as transportation, handling, different plant layouts, interior materials, finishing, and labor. In many developing countries, the use of local labor in construction may be convenient and often desired for political and social reasons. Normally the labor costs are much lower than in the more developed countries, and this substantially reduces the overall costs.

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The system which is selected should be composed of parts that are moderately heavy and easy to handle, load and unload, transport, and erect. Erection should be simple and possible even for unspecialized workers.

The exterior components, subjected to weathering, should be of durable, non-degradable material of good quality. The interiors should be adaptable to different coverings to fit the requirements of the users or the availability of materials.

All these conditions can be met by an open system formed by a set of discrete components rationally designed in cold formed steel and combined with interior covering material as described below.

2.2 Low Cost System

Besides being easy to transport and erect, the fabrication cost of the selected system should be as low as possible, provided that acceptable quality levels are maintained.

A Standard Components System (SCS) has a cost advantage in the industrial process over a Special Designed Components System (SDCS). Even if the design is optimized, SDCS requires more work space, machinery, fabrication time, and working capital than the SCS. The production cost consists of the direct cost and the indirect cost. In accordance with cost theories, the graphical representation of the cost is portrayed by line AB of Figure 1, in which OA represents the indirect cost, and the slope of AB the direct cost per unit produced. Line OC represents the gross income proportional to sales. Point E is the equilibrium point that designates the quantity, Qe, over which benefits may be expected.

For industrial production, according to SDCS, the indirect cost, OA, is relatively high, because space, installation, machinery, and a broad organization must be considered. When the SCS is employed and products available in the market are used, the indirect cost can be reduced to only a part of that of SDCS. This is shown by line A'B' on which another equilibrium point, E', is established at a much lower quantity, Q'e.

Consequently, for the same price line, OC, benefits are possible for much lower production levels. The price can be reduced drastically by passing to a line, such as OC', with another equilibrium point E''.

The difference between line OC and OC' represents the price reduction that can be obtained through the SCS.

Another interesting fact is that the same gross benefit, GB, (Fig. 1) can be achieved with lower sales quantities, such as Q's < Qs.
This analysis shows that the investments and working capital needed are lower in the SCS for same capital revenue rates. The time to produce houses is reduced by the availability of the components in the market based on the normal stock of these products. Because standard products are normally produced in high quantities, the cost of stocking is already included in their cost on the competitive levels of mass production.

The fact that the production of houses can depend on the availability of stock and the production capacities of important industries of standard cold formed products indicates that the production time of houses can be shortened considerably. The reduction and simplification of the production cycle inside a manufacturing plant reduces the cost and financial requirements. Production speed depends basically on the capacity of the basic industries, and this reduces the inertia of the production cycle. The capacity for prompt delivery makes the builders less dependent on their own industrial installations. The consequence of this is that important quantities can be produced at a much lower investment. This is probably the most important cost reducing factor favoring the SCS.

3) MAIN COMPONENTS

In an "open system" based on discrete components, the following basic parts are distinguished:

- structural framing
- roofing
- external wall covering
- internal wall covering
- partitions

Cold formed steel shapes offer the most versatile solution for structural framing. For the external covering of the walls, the conventional solution of corrugated sheeting has been used since the end of the last century for economic reasons, as shown in Figure 2, which is a photograph of "LA BOCA", an old quarter of Buenos Aires, that was constructed around 1900.

It should be remembered that the use of corrugated steel sheeting for exterior walls is still one of the most trustworthy exteriors for buildings in any climate. A well sealed galvanized or aluminized steel siding is an excellent barrier for the exterior wall of a house because of its following qualities:
Because of all these advantages, steel sheeting deserves a "revival" as a building material for houses, especially in light of the many new technical possibilities applicable today. One of the most important structural concepts that can be applied to steel sheeting nowadays is the so-called "skin action", which allows for an increase in the overall efficiency of the material through its strength and stiffness as a diaphragm, which serves as a substitute for structural framing in its resistance to lateral forces.

The variety in the shapes of sheeting now available, such as trapezoidal profiles, makes it possible to select facings of adequate appearance. It should therefore be possible nowadays to use standard sheets in order to design an attractive exterior facing for a low cost house and still employ a basic low cost solution. By redesigning and replacing the facings of existing structures, the slum-like appearance of the dwelling shown in Figure 2 can be given a more modern looking appearance.

For the interior, there are no restrictions in using different materials provided they have adequate strength and qualities. Different materials, such as chipboard, plywood, gypsum board, hardboard, timber, or plastic can be employed.

Internal partitions are not a special part of the system. Conventional gypsum board partitions may be used. When using other materials, structural framing can be the same light steel construction that has proved to be the most practical for gypsum partitions.

The freedom to select interior material for walls and partitions provides a special flexibility to adapt to different public tastes, economic capabilities, and preferences.

In many cases, these coverings can be made with local materials if this reduces the overall cost of the product.

4) SELECTION OF COMPONENTS

Standard cold formed steel construction products are competitive, because they are produced by industrial methods of high productivity, and the manufacturers are stimulated by strong competition. This is the case for corrugated metal sheeting, which is probably the most competitive product of them all.
The principle that has been consistently pursued by the author is that the lowest cost should be transferred through the cost advantages of standard products to the final product.

The most important selection is the sheeting of the exterior walls. It must have a good appearance, offer a resistant face, not be subject to damage when slightly bumped, and be highly efficient, that is to have a reduced loss in its manufacture and lappings. It is well known that standard corrugated sheets have the highest efficiency factor and therefore solve the problem of providing the lowest cost. But its industrial-like appearance is not acceptable nowadays for a house.

Among different trapezoidal sheets available in the local market in Argentina, the author selected a sheet produced by ARMCO under the trade name of ECONOPANEL (Fig. 3). In the normal position for roofing and siding, the narrow ribs should go on the outside, but it was found by the author that by inverting the sheets and connecting the ribs to the purlins, the wider strips offer a nice plank-looking surface (Fig. 4), which gives one the impression of solid construction. For uniformity, the same type of sheeting can be used for the roofing but in the normal position with the ribs outside.

For the structural framing, normalized, cold formed, standard steel units which are galvanized for better protection against corrosion can be used.

For the interior covering, as already explained, any conventional board may be used provided its stiffness and quality is acceptable.

5) DESCRIPTION

5.1 Basic Structural Idea: Skin Action

The basic structural idea that governs the design of this type of house is the full utilization of the skin action of the exterior sheeting. Although the possibility of full employment of the skin action deserves an important place in design of future houses, the author feels that in the construction of important structures, skin action should be considered with care.

For example, the author used skin action only as a secondary safety feature in the 200 ft. wide hangar for AUSTRAL Airlines in the Buenos Aires Airport (Fig. 5). In the less important parts, such as the 42 ft. wide sliding doors, the skin action was totally utilized by employing the siding as a structural component of the light, space truss structure of the doors.

Considering the limited proportions of houses, the application of full skin action would be structurally adequate. Also, through use of the skin action, the structural weight would be substantially reduced.
In the discrete dimensions of the box formed by a rectangular plan, skin action is capable of resisting all the lateral effects of wind or earthquakes without the need of heavier gages for the sheeting.

All the sheets for the roof and walls can be fastened by standard No. 14 screw fasteners to a light steel frame, converting the entire unit into a rigid and resistant box.

Computation of the fasteners has been performed in accordance with the criteria outlined in references 1 and 2. The shearing stresses in the sheeting have been verified by following the recommendations of AISI Specification (3).

It is interesting to note that a normal house can resist winds of 200 km per hour (124 mph) and that this condition is more severe than an earthquake. The author's idea is that a high reserve for dynamic lateral loads is obtained by the ductility that can be developed in the hundreds of connection points of the skin fasteners.

5.2 Structural Framing

As already stated, the lateral structural strength is provided by skin action and not by the steel frame, which is composed of posts, girders, and purlins, which are connected by bolts.

Local roof loads are resisted by the bending of the roof purlins and girders and transmitted to the posts.

Lateral loads are resisted by the bending of the wall purlins and posts and transmitted to the frame girders, where the loads are passed to the sheeting by the fasteners.

It is interesting to point out that in many existent buildings, structural frames sometimes do not work as designed. Structural bends made by slender profiles always have a flexibility that is greater than the slab-like stiffnesses of the end walls, if these are covered by sheets through fasteners. In such cases, structural action will depart seriously from the designer's conception. Skin action will exist in the structure, even if ignored by the designer. That is why in such a structure that has all the sheeting fixed by fasteners, the skin action cannot be ignored and should be considered as the main structural feature.

5.3 Wall Sheeting

As previously stated, the exterior walls are made up of ARMCO sheets locally called ECONOPANEL, 24 gage, aluminized or galvanized in 7 to 8 ft. lengths.
The sheets are placed in an inverted position with the narrow ribs facing inside and connected with No. 14 hexagonal screw fasteners to the wall purlins.

This unusual arrangement provides, besides a good appearance, a simulation of heavy vertical planks (Fig. 4) and the advantage of ample vertical cavities favoring insulation. It also limits the thermal bridge to a small contact between the narrow ribs and the purlins.

Because the heads of the screws are hidden in the shadows of the ribs, the industrial-like appearance is avoided.

To facilitate the placing of the wall sheeting, the purlins are prepunched on a 190 mm module throughout the contour of the house. The correct placement of sheets is therefore easy and fast.

The system permits the location of the sheets in any desired position of the contour. With the windows and doors modulated to a multiple of 190 mm, they may be installed in any place. This provides a high flexibility to the system.

Below the windows, the sheets have to be cut in half and fixed to the middle purlin, which also supports the window frame.

One interesting detail is the solution for finishing the corners. Here the sheets are simply bent alongside a rib. Thus, the use of special flashing is avoided, and a compact handsome appearance is provided (Fig. 6).

5.4 Openings

The openings are normalized to the wall moduli. Widths are 4, 5, 6, and 8 corrugations measuring 760, 950, 1140, and 1520 mm (approximately 30, 37.5, 45, and 60 inches). The doors and windows should match exactly with these openings.

Once the sheeting is erected, the desired window and door frames can be easily inserted, sealed around the edges, and securely fixed by fasteners to the structure.

5.5 Internal Covering

The internal faces of the purlins are flush with the posts and allow the direct installation of insulation sheets (glass fiber) and a variety of alternative materials, such as shipboard panels, timber, or gypsum planks. These can be fastened by tapping screws with sunken heads directly to the purlins. The insulation is thus pressed between the purlins and the panels.
The same solution can be applied for the ceiling, but in this case, the insulation is located on top of the purlins. The ceiling has the same slope as the roof. Before attaching the ceiling panels, the electric tubing is installed in the roof spaces between the purlins and the ceiling panels.

All the boards for the walls and ceilings are sent to the field ready to install, cut exactly to the proper dimensions, prepunched, and marked. Complete drawings and instructions allow for easy installation.

5.6 **Partitions**

Internal partitions are designed for the installation of different types of covering, such as chipboard, hardboard, gypsum board, plywood, or other materials.

The framing is three-inch light gage steel channels normally used for conventional gypsum panels.

The panels are sent in pieces either to be assembled in the field or shop assembled in sections ready to install. These are conveniently marked to allow for easy and fast installation.

The panels include vertical electrical ducts in which electrical wiring and switches can be placed and provided with covers.

For installation between the bathroom and kitchen, a sanitary panel is provided with all the water and sewer pipes ready to be connected to the public services.

5.7 **Erection**

The erection of the kit is completed in a short time. Actual estimation is 200 to 300 hours to erect a 100 sq meter house (approximately 1075 sq ft) completely. The erection of exterior walls and roof, including the openings, can be done in less than 40 hours; that is less than two days for three workers.

The erection of all interior coverings and partitions may take the same crew a few days more. Finishing and paint retouching must also be considered.

The system requires sound plant engineering and careful preparation of all the pieces. All parts should be fabricated to adequate tolerances, and clear specifications, material lists, erection drawings, and instructions should be prepared to avoid troubles in the field.
6) **FLEXIBILITY**

The use of modular components based on a rather reduced dimension, such as 190 mm (7.48 in.) makes for a highly flexible design that can be adapted to practically any plant layout. Exterior windows and doors can be installed where needed, and the same can be done for the installation of internal partitions.

Houses can be designed from a very modest one that has less than 300 square feet of space up to houses of 1500 or more square feet with sophisticated interior finishing.

The same system can be easily applied to the design of dormitories for camps or schools (Fig. 7). In these cases, the units can be totally dismantled and reused. If dismantled, the pieces can be stored in a rather reduced space.

7) **EXPERIENCES**

Before designing this type of house, the author designed and supervised the fabrication, under license, of some small, rather sophisticated dwelling units for weekend lodging. A portable hexagonal cabin (Fig. 8) and later a local patented pentagonal cabin (Fig. 9), which could be erected in three minutes, were designed and constructed. These included interior equipment.

Some hundreds of these units were produced and are now in service in weekend camps around the country. Both types are made with special cold formed steel products and include insulation and filling in boards.

After these experiences, the author became interested in the construction of real houses.

The lessons that were learned from these experiences can be summarized in the following recommendations:

1) The components of a house should be standard products that are available in the market at competitive prices. Each specially designed part, which needs to be custom made, increases the costs and the time of the production cycle.

2) Completely assembled units or panels require a large amount of covered space, machinery, handling, and equipment, which means capital investments. Therefore, the more sophisticated and complete the product, the higher the investments. To reduce capital requirement and risks, the simpler the system, the better.
3) The cycle to produce each house should be as short as possible, even if this means a transference of man hours from the shop to the field. The shorter the cycle, the bigger the possibility of reducing the circuit. This consequently increases the revenue of money that is in that circuit.

4) Following the last recommendation, it is highly convenient to use standard materials, normally stock material such as sheeting, profiles, and boards, that are produced by important industries. This permits these industries to scale their production of houses to higher productivity levels, which are practically impossible to reach by other means.

5) The elaboration of parts should be as simple as possible and the work limited to cutting, punching, and protecting.

6) Elaboration preferably should be done by others at competitive prices. In this case, the plant would be limited to a shop where material is received, checked, selected, marked, and stored and later packed and delivered.

Some components as roof and wall sheeting may go directly from the rolling mill to the site.

7) All components should be designed so that they can be handled by one person, never more than two.

The use of handling equipment normally employed in advanced countries is not practical, because such equipment is often not available or is too expensive in most places of the developing world where houses are needed. Heavy pieces are a handicap for any system, if they are intended to be as universal as possible.

Finally, the author is proud to mention that at the time he was preparing this paper, the production of these houses had already started and that the above mentioned recommendations were producing results that confirm the adopted criteria. Some of the houses, which were built as prototypes, have been in service with good results for more than one year.

8) TEST PERFORMED

Some tests that were performed locally produced results that are of interest.

8.1 Impact Test

Figure 10 shows the test arrangement in accordance with local specifications. This is an empirical test to measure the capacity of a panel to resist the impact of a weight of 30 kg (66 lb.) dropped from different heights.
Panels composed of timber, gypsum, or concrete normally fail completely before the weight reaches its highest position.

The composed wall panel intended for a house made of cold formed sheeting and purlins with a 13 mm (0.5 in.) chipboard interior covering exhibited great strength. It was impossible to destroy the panel with the actual test installation.

This proves that this type of panel has a very high energy absorption capacity, which is much higher than other panel systems.

8.2 Water Tightness

In this test, the panel is irrigated from outside. The panel is fixed to a sealed frame in the contour. The quantity of water or humidity that passes or is absorbed by the wall is measured during an established period of time.

The result was a 100% tightness of the panel. No water passed nor was absorbed at all by the panel. The panel was classified as excellent.

9) FUTURE DEVELOPMENTS

The impact test that was performed certifies that the panel’s greater strength may be in excess of what is needed.

In designing the framing elements, no interaction was taken into account for either the external sheeting or the interior panels when loaded normally to the wall. When wind loads or snow loads act on the panel, certainly the covers will interact with the purlins.

In the future, it would be advisable to evaluate this interaction and probably reduce the frame member thickness. Actually, some panels for high wind or snow loads become too heavy and this increases the cost. It would be convenient from a practical point of view to take interaction into account and to normalize the thicknesses to a uniform gage for all members.

Another possible improvement would be to change all the C profiles used in the design to a Z type. This would allow the profiles to be nested, thereby reducing the space needed for shipment.

Actually, the panel for between the bathroom and kitchen that is called the "sanitary panel" contains all the plumbing in its interior. This should be revised, because some problems arise when the plumbing fails, and it is difficult to repair. Besides this, the sanitary panel is an expensive item. In the future, a sanitary "channel" will probably replace this panel. That is, it will be a box-like section with a cover that will contain all the tubing. This can then be fixed to the faces of the wall in any place.
This solution will provide three advantages: a lower cost, more accessibility to the tubing, and more design flexibility. (The bathroom does not need to be adjacent to the kitchen.)

10) CONCLUSIONS

A house based mainly on the components of standard cold formed sheets and shapes has been described. The fundamental ideas have been to avoid the use of specially designed shapes and to obtain an acceptable product starting from standard cold formed shapes available in the market at competitive prices.

It is the author's conclusion that the design presented could provide a broader incentive to use cold formed steel products and make accessible at a lower cost a durable and handsome house for a greater number of people in a world of increasing populations and needs.

Acknowledgments

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REFERENCES

1. Chockalingam, Paul Fazio, and Kinh Ha, "Strength of Cold Formed Steel Shear Diaphragms", 4th Intl. Specialty Conf. on Cold Formed Steel Structures, St. Louis, Mo., 1978.


FIG. 1 - Cost Analysis Graphs
Fig. 2 - "LA BOCA" quarter of Buenos Aires
FIG. 3 - ECONOPANEL SHEET (ARMCO ARGENTINA)

Width = 760 mm. (29.9"

3.15 mm. (1/8"

25 mm. (0.98"

60 mm. (2.36"

190 mm. (7.48"
Fig. 5 - Hangar of Austral Airlines, Buenos Aires Airport (Courtesy of SINCO S.R.L.)
Fig. 7 - Campus Dormitories
Fig. 8 - Hexagonal cabin (courtesy of Proveeduria Deportiva)
FIG. 9 - PENTAGONAL CABIN
PENDULUM.

Weight
30 Kg (66 pd)

TEST DATA

$h_{\text{max}} = 3,00 \text{ m (9' - 10'')}$

Energy = 90 da J

FIG. 10 - IMPACT TEST FOR PANELS