ECONOMY THROUGH EFFICIENT STRUCTURAL SCHEME

Carlito P. Talaboc, Ph.D.

Introduction

Economy of building construction starts from the drawing board. The decision of the structural engineer as to what scheme to adopt plays a very vital role in any construction project. It is this scheme that dictates economy or extra expense. Unfortunately, the clients are not aware about this and very often the making of the whole plan is left entirely to the architect. The usual architect's fee of about 3% to 8% of the total cost of the project is supposed to cover everything including structural design. To save money, the architect goes to the lowest-paid civil engineer and sometimes does the structural design himself especially if the building is only three stories or less. What the owner does not know is that the structural element of his building is oversized and that he has to spend more money for structural framework than what is really needed. Of course there is nothing wrong with this practice as long as the building is safe under the design loads. But, when we talk about saving construction materials for the nation, that is something else. Why should we put more materials than what are needed? As structural engineers, it is one of our duties and responsibilities to design the most efficient and economical structural framework for any given building.

Accurate analysis alone is not sufficient to. attain economical building. It is the choice of designs of structural scheme that is the root of the economy of construction . From the structural scheme mathematical models are drawn. With the availability of computers, analysis of these models can be done accurately at considerable speed. What it takes weeks and months by hand computations can be done in minutes by digital computers. Hence, analysis is not really a problem. It is the development of the structural framing scheme that needs serious attention and intensive discussions among structural engineers.

This paper presents ideas on how to develop efficient structural schemes. These ideas are not new to most engineers but somehow, for some reasons, they are forgotten in practice, based on the writer's observation of actual constructions going on across the nation. This paper also presents some of the existing buildings designed by the writer and illustrates how materials were actually saved through efficient structural schemes.

What is efficient structural scheme?

Efficient structural scheme means putting together a lesser amount of materials to support a given load. This includes the choice of the kind of materials and the manner in which they are arranged to form the structure. Efficient scheme varies from one kind of building to another depending on the actual situation.

Optimum structural design is another consideration. This comes after the structural scheme has been fixed. In other words, structural scheme is one of the constraints in optimum structural design. In most cases, it is the aesthetic design established by the architect that governs over the optimum design. Although structural scheme is sometimes controlled by the architect, an efficient scheme always exists and the structural engineer has to find it under the given constraint.

There is a good number of techniques used in the establishment of efficient structural schemes. Some of the most common are: arch and shell action, interaction of truss and columns, shear wall action; utilization of concrete above, below, and beside door and window openings; proper analysis on the use of footing tie beams, elimination of intermediate piers in bridges, the use of vertical trusses with attractive patterns in high-rise steel buildings, and many more. Other techniques would just appear in actual practice as the need arises. The ability of the structural engineer to employ an efficient scheme on the spot is a very important factor in structural design.

Arch action

Figure 1[1] shows the existing Pepsi Cola Warehouse, located in Mabolo, Cebu City, constructed sometime in 1973. The original design, Fig. 1a, which employed simple fink trusses required 56 tons of steel. The writer was given the opportunity to redesign the structure. The revised scheme made use of continuous arch trusses with a semi-space truss pattern as shown in Fig. 1b. The arch action makes the system extremely efficient and reduces the total weight of the steel to 32 tons. This means that 24 tons of steel were actually saved in the redesigned construction. Due to inavailability of a computer at that time, analysis of the mathematical models was done by hand calculations using the principle of virtual force method. The analysis alone took 14 days. Now, with computers, the same analysis could have been done in hours or maybe minutes.

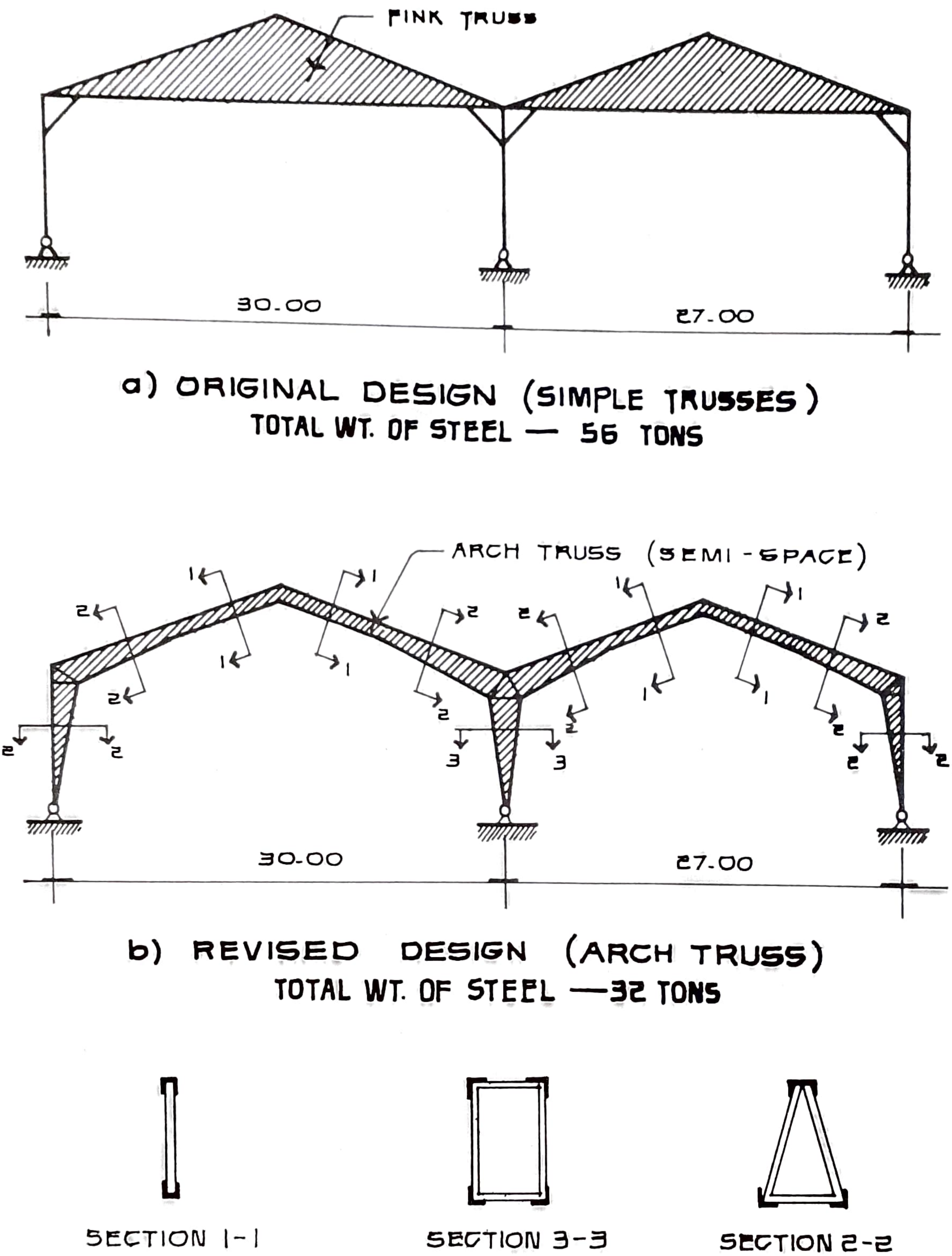


FIG. 1. PEPSI COLA WAREHOUSE, CEBU CITY, 1973
EFFICIENCY THROUGH ARCH ACTION

Another efficient structure, which made use of the bow-principle is shown in Fig. 2. The Sy Beng Tee Warehouse in Pala-o, Iligan City was constructed sometime in 1974. The writer designed the arch truss with a tie rod to take care of the kicking force generated by the action of the arch. When the tie rod was given an initial stress, it induced a prestressing effect in the arch. This effect is opposite in sense to the stresses due to gravity. Because of this phenomenon, the stresses due to gravity are reduced, and this makes the system very efficient.

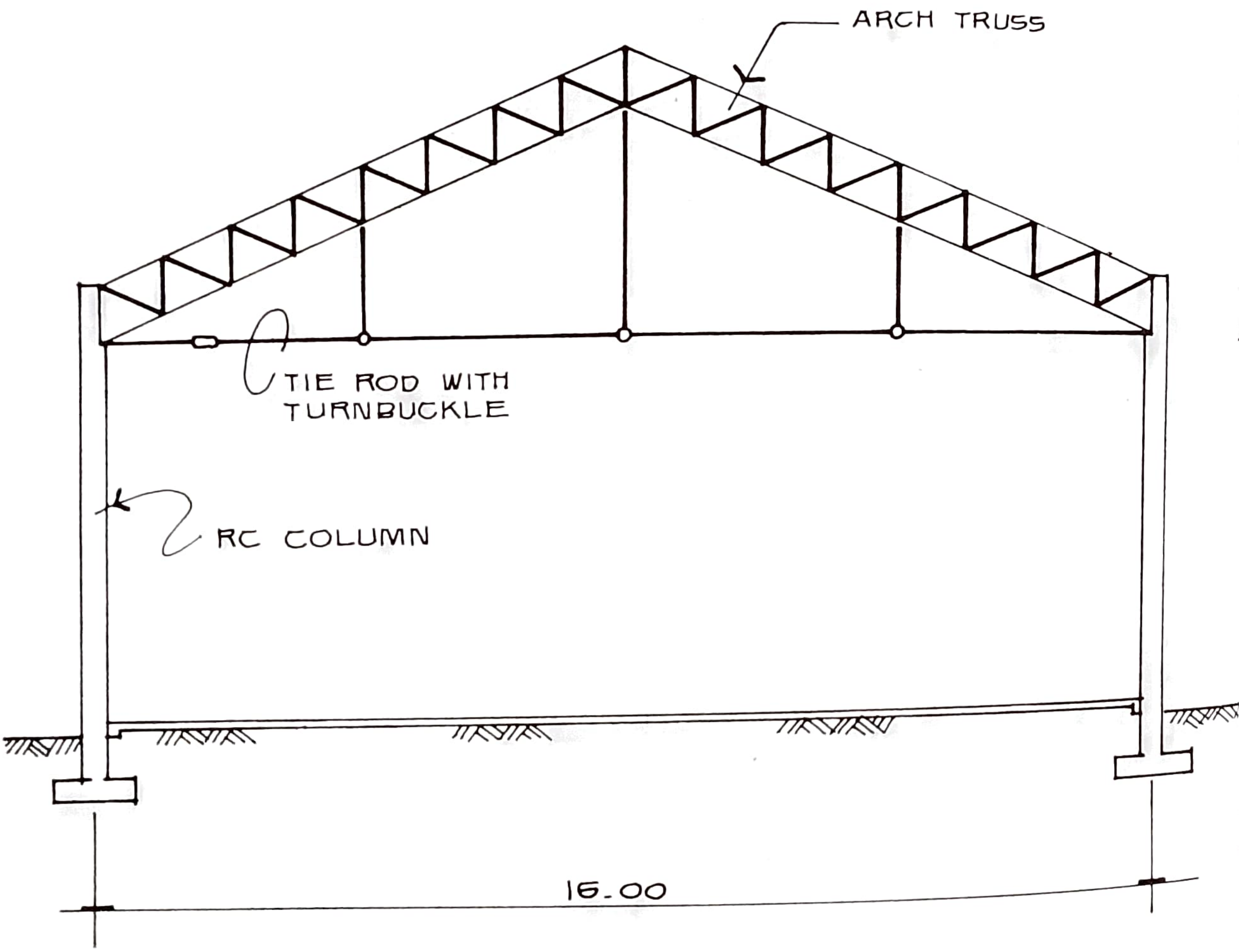


FIG. 2. SY BENG TEE WAREHOUSE (1974)
(BOW-PRINCIPLE) PALA-O, ILIGAN CITY

1 The List of Figures is given in the Appendix found at the end of the report.

Interaction of truss and columns

Figure 3 shows the existing FB Serate Warehouse, located in Barinaut, Iligan City. Designed by the writer in 1984, the structural scheme made use of arch action plus the interaction of truss and columns. The system was so efficient that only flat bars reinforced with round bars were used in the arch truss. Analysis was done with the use of a digital computer through the program developed by the writer. The program which can analyze a combined truss and framework system is called truss-frame analysis.

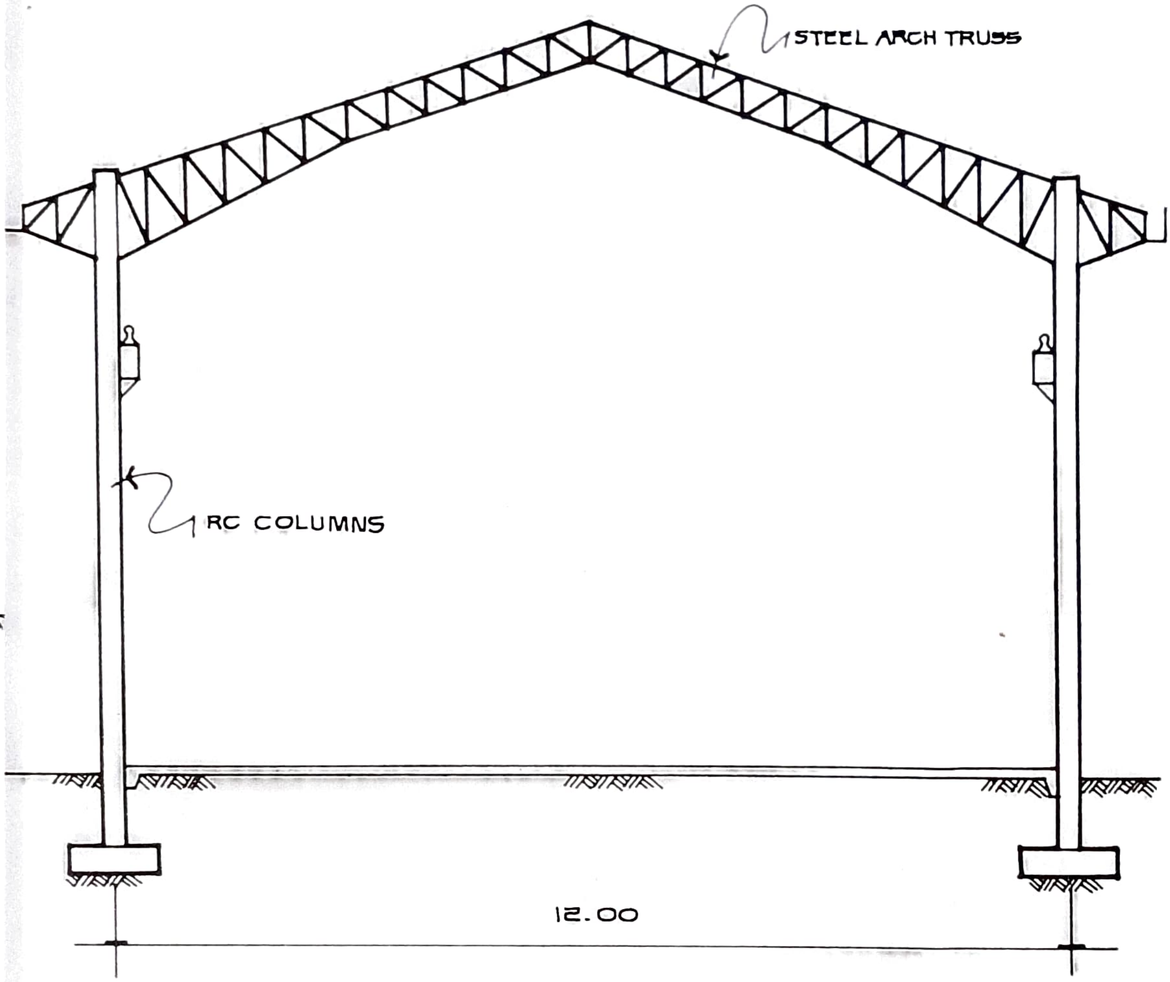


FIG. 3. FB SERATE WAREHOUSE, BARINAUT, ILIGAN CITY 1984. EFFICIENCY THROUGH ARCH ACTION & CONTINUITY AT TRUSS-TO-COLUMN CONNECTIONS.

Another very efficient structure is shown in Fig. 4. The Lanao Community School located in Pala-o, Iligan City was constructed in 1987. Efficiency was attained through arch action and interaction of truss and columns. Analysis was done using a digital computer with the same program of truss-frame analysis developed by the writer. The member sizes were so small that local contractors at first thought the system could not withstand the design loads. It turned out that the trusses were actually very strong even though the members were super-slim.

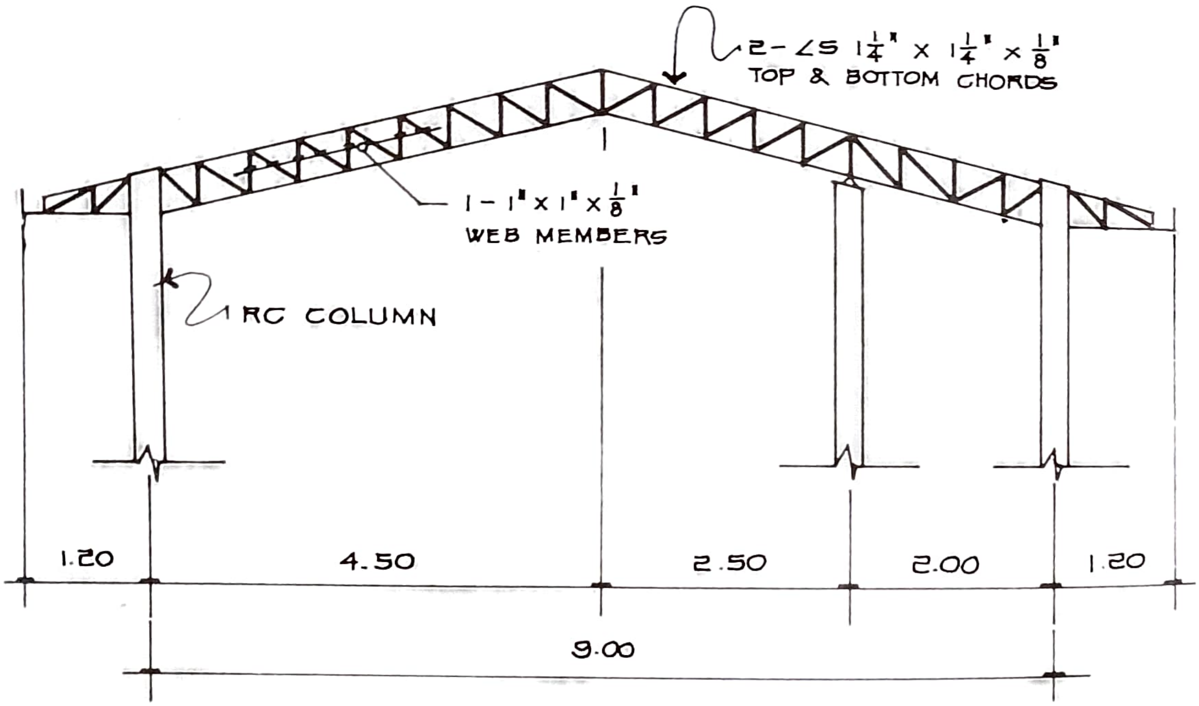
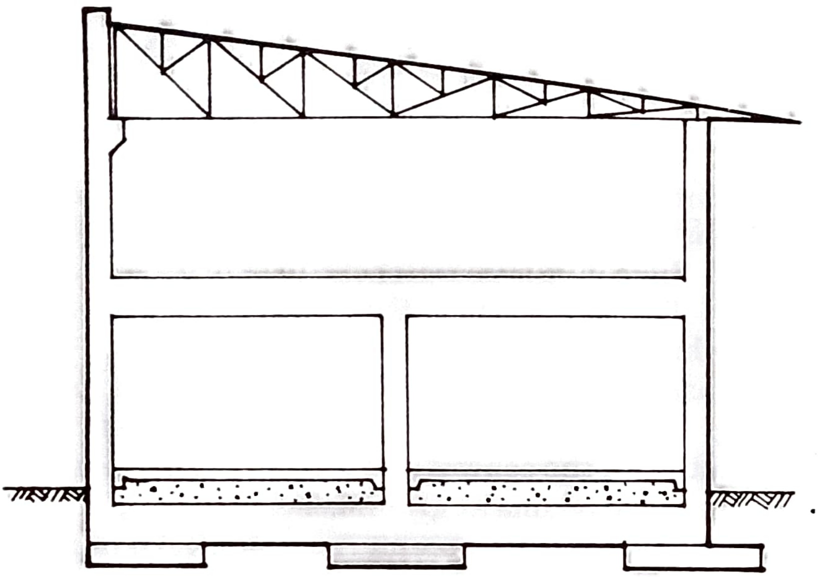


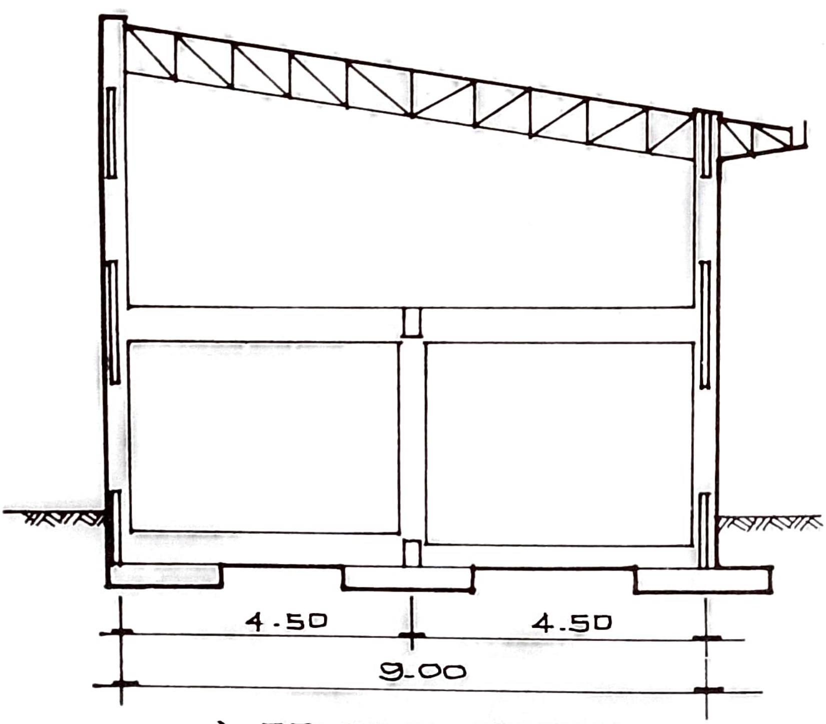
FIG. 4. LANAO COMMUNITY SCHOOL, PALA-O ILIGAN CITY, 1987. EFFICIENCY THROUGH ARCH ACTION & CONTINUITY AT TRUSS-TO-COLUMN CONNECTIONS.

Utilization of concrete above, below, beside door and window openings.

Figure 5 shows the existing Hammer Building on Cabili Avenue, Iligan City. The building was constructed in 1987. The writer redesigned the structure to include earthquake resistance. The original scheme (Fig. 5a) is not efficient since the simple truss on the column and corbel does not have the rigidity to support lateral loading. The columns in the second floor have to act as cantilevers inducing very high bending stresses at column bases. Furthermore, the shape of the simple truss is not efficient at all in resisting the gravity loads. The revised scheme (Fig. 5b) is extremely efficient because of truss-column interaction and the utilization of the concrete above, below, and beside door and window openings. The thin deep beams at ground, second floor, and roof levels used very little amounts of steel reinforcement. A considerable number of CHB for walling was saved because the deep beams occupy wide spaces in the wall areas. Lateral buckling of the deep beams were checked. The floor slabs which were cast monolithically with the deep beams act as lateral stiffeners. Efficiency in this scheme is attained generally through the interaction of all the elements comprising the global structural framework.



a) ORIGINAL SCHEME



b) REVISED SCHEME

FIG. 5. HAMMER BUILDING, CABILI AVE., ILIGAN CITY, 1987
TRUSS-COLUMN INTERACTION & UTILIZATION OF CONCRETE ABOVE, BESIDE DOOR & WINDOW OPENINGS.

Shell action

Shell action is commonly employed in the design of reinforced concrete shell structures. Shells vary from the simplest form which are the shells of revolution to the developable shells such as cylindrical and folded and finally to the non-developable shells such as hyperbolic-paraboloid and elliptic-paraboloid shells. An analysis of shells is rigorously covered in a standard graduate program course about shell structures. Shell action is not limited to reinforced concrete construction. The lamella roof framing shown in Fig. 6 is an example of employing shell action in steel structures. This building is the Baptist Conference Church located in Iligan City. The building is still under construction. The writer designed the lamella framing making use of shell action. The typical lamella element made use of 12-mm diameter deformed bars as shown in Figure 6.The original design which was simple fink trusses with knee braces to take care of the lateral forces, required P200,000 for the roof framing alone. The lamella scheme needed only a little less than P80,000 including paint. The other benefits derived from this scheme are the acoustic effects, aesthetic beauty and the amazing strength of the framing. When the scaffoldings were removed a maximum displacement of less than 1/8 of an inch was observed. Displacement under the service loads is even lesser that engineers in the know consider this to be negligible.

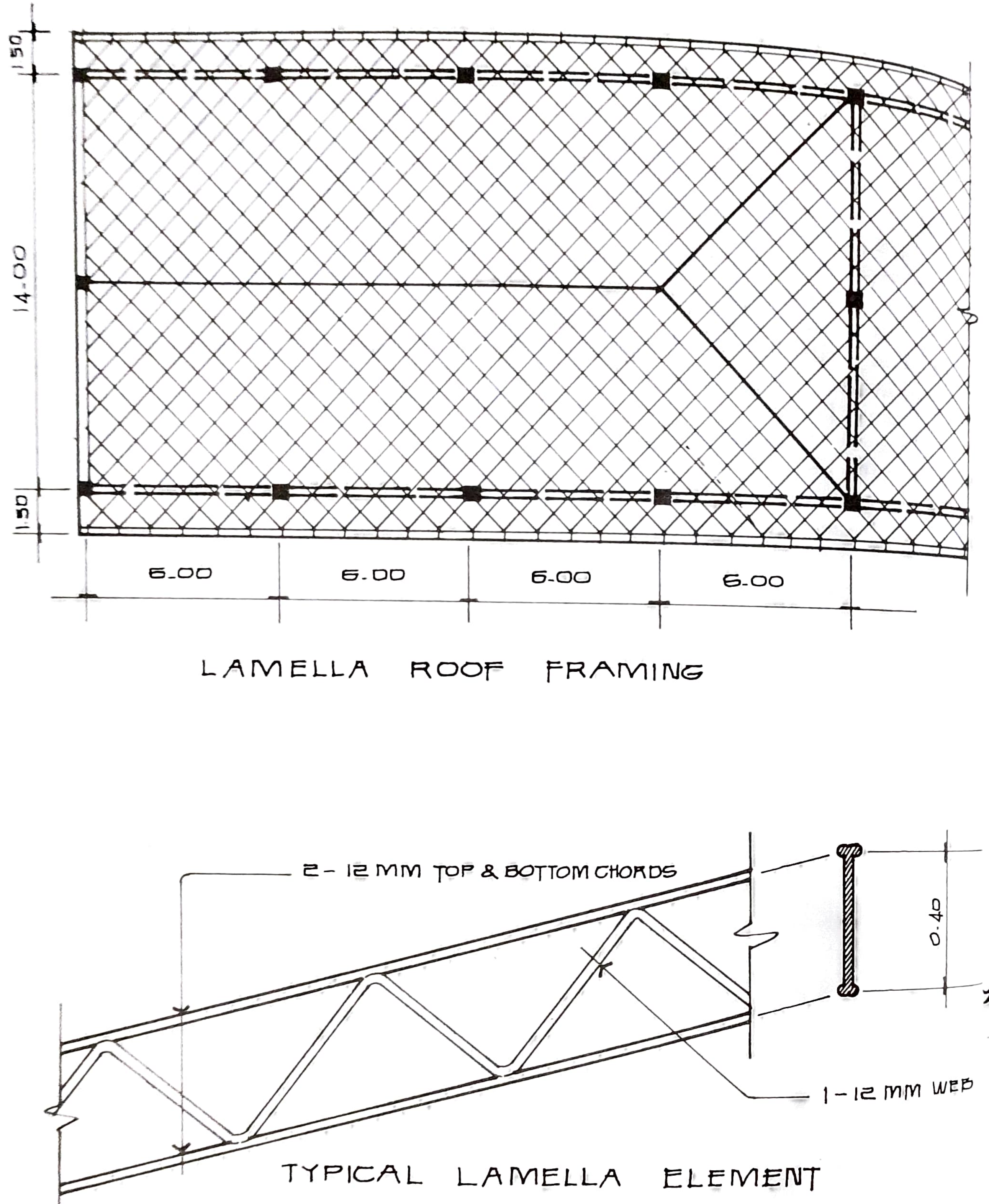


FIG. 6. BAPTIST CONFERENCE CHURCH, ILIGAN CITY, 1988
EFFICIENCY THROUGH SHELL ACTION.

Elimination of intermediate piers in bridges

Figure 7 shows the proposed structural scheme for the Tambacan Bridge in Iligan City. The project is still under negotiation. The proposed scheme eliminates the construction of intermediate piers which could be very expensive because these piers have to be constructed on piles and piles are very expensive to drive especially in the middle of a deep riverbed. Furthermore, maintenance of these piers could be troublesome due to erosion brought about by the river current, especially during heavy floods. The arch action of the main parabolic arch makes the system efficient and hence reduces the amount of construction materials needed. The absence of the intermediate piers eliminates obstruction for floating logs especially during floods. Floating logs could be disastrous to bridges.

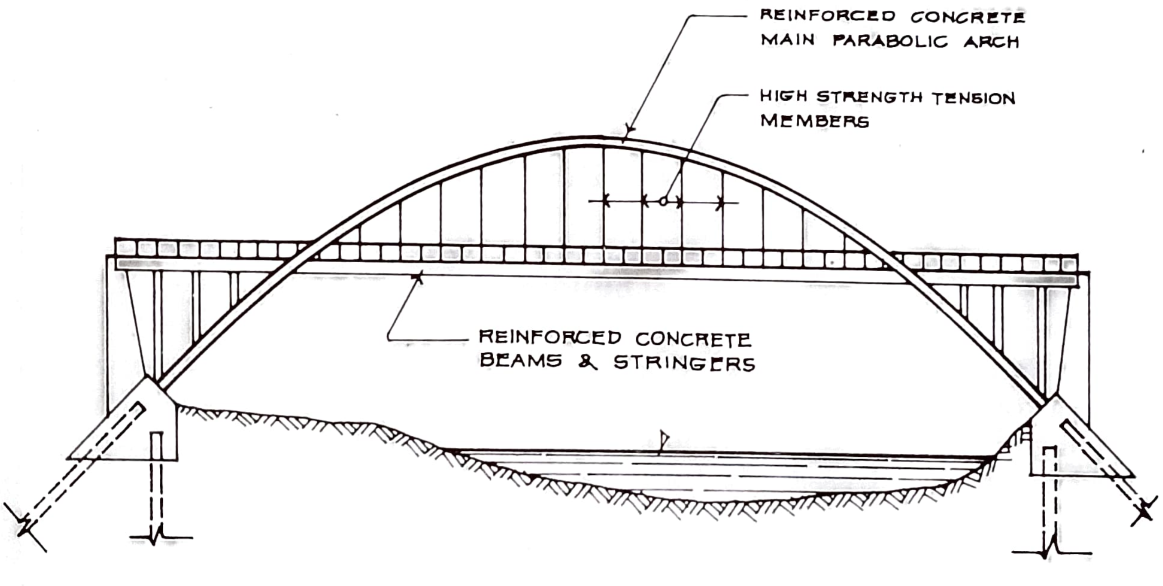


FIG. 7.. PROPOSED STRUCTURAL SCHEME FOR TAMBACAN BRIDGE, ILIGAN CITY.

Shear wall action

Shear wall action makes the building efficient in resisting lateral loads brought about by earthquakes and wind forces. The very high lateral stiffness of the shear wall relieves the stresses in beams and columns under the action of lateral loads. Economy is realized since the beams and columns of the framework become smaller in size . Furthermore, solid concrete shear wall costs about the same or even less than a CHB wall, neglecting the cost of frameworks.Provisions of shear walls become more economical when these are precast, for the cost of formworks and scaffoldings can be virtually eliminated.

Proper Analysis on the use of footing tie beams

When footing tie beams are included in analyzing the framework as a whole, they attract movements relieving the high stresses in the beams and columns of the ground floor. The tie beams, of course, become a little larger but at the same time the beams and columns become smaller. Since it is easier to pour concrete in the tie beams than in the elevated beams and columns, aside from the reduction in the sizes of the latter elements, economy is somehow attained. The most important thing about this scheme, however, is the determination of the actual stresses the structure is supposed to respond to under the design loads, thus allowing the engineers to provide the proper sizes for the members. This leads to the construction of a safe structure and economy is achieved since the actual response of the building is easily determined.

The use of vertical trusses with attractive pattern in high-rise steel buildings

Vertical trusses in high-rise steel buildings act as a huge shear wall, since a truss is very strong in resisting loads applied in its plane. Many buildings in the U.S., especially in the earthquake-belt areas were constructed employing vertical trusses of attractive patterns. The interaction of the usual beam-column scheme and the vertical trusses together with the shear walls derived from elevator shafts and blind walls form a system which is very efficient in resisting lateral loads. The analysis of this system can be handled easily with computers using the standard stiffness or displacement methods of frame analysis.

Summary and Conclusion

Other techniques for efficient structural schemes could just evolve in actual design situations. As long as the structural engineer is well-equipped with the basic principles of structural design, he can always develop an efficient scheme favorable to a given project.

There could be huge savings in the construction business in the Philippines by merely utilizing efficient structural schemes. Unfortunately, the owners are not aware of this. If we could only educate the people involved, then we can construct more buildings and bridges with an almost uniform amount of money. It is high time to cope with the ever advancing technology in design and construction.

This paper illustrates actual savings of materials through efficient structural schemes. Everybody should do the same in order to help our nation recover from the economic crisis faster. Of course, this is not a solution to the economic problem but for sure, it could be helpful in achieving this goal.