termined, and then careful calculations as to the stability of the pier must be made, and should it be found deficient, as is often the case with deep trusses, or where bascule or lift spans are employed, then it must be increased in length of base until the maximum allowable stresses and pressures are not exceeded.

Then by means of the cost of abutments, piers and spans, the relative costs of various designs may be determined; the weight of the spans to be calculated from reliable formulae or from actual stress and section diagrams. The design of the approaches may be a factor in the relative costs, and in such cases must be included in making the comparisons.

The fact that some consulting engineers make out certain designs to be the cheaper, when comparing them with other designs made up on an entirely different basis, both as to the character of the construction and the real factors of safety, should make any one suspicious of the character of the services offered and disbar such engineers from reputable practice.

The type and design of the superstructure is such a large factor in its cost that this must be fully decided upon before beginning any of the above investigations, and then all designs be compared upon a common basis. Where the grade is high above the stream, with plenty of clearance for floods and navigation, deck spans of some type are, of course, the most economical to employ. Where the bridge is high or falsework expensive for other reasons, it may be best and cheapest to use an arch or a cantilever design, and where very long spans are necessary, either the cantilever or suspension bridge must be used. Where the clearance for high water or navigation is limited, through trusses must be used, although it will often be best to use cantilever spans instead of simple trusses. Through arches or half-through arches may often be employed with good results both architecturally and economically.

The economical design of the superstructure of a bridge requires careful consideration as to the style of trussing, the panel length, and the truss depths. Longer panels and deeper trusses are more economical for modern heavy loads, but for plate and riveted lattice girders the depths are usually much less than for regular trusses. The span lengths for cantilever bridges should always be decided by careful mathematical analysis, as well as the lengths of the cantilever arms, suspended spans and depths. The height of towers and the depth of stiffening trusses for suspension bridges must also be carefully analyzed.

The design of movable spans should be carefully considered, not only with regard to first cost, but as to cost of operation and maintenance as well, but do not get the idea that revolving draw spans are out of date, for in many locations they are the cheapest and the best to employ. Then there are locations where bascule spans are the best from every point of view, but where used they should harmonize with the remainder of the structure, if there are additional spans, but in any case those forms must be abandoned that have no pretentions to architecture or beauty, and the same thing may be said with regard to other types of movable spans.

The details for ordinary spans have reached a practically permanent basis, so that standards, at least as to type, are usual. Where the structure is of unusual size, like the Blackwell's Island bridge, the Forth bridge, or the Hell Gate arch, each member must be the subject of critical analysis and study.

Lack of such study and analysis was the cause of the failure of the first Quebec bridge, although the writer's one-time assistant, the late A. H. Heller, had fully covered the points in question in his book on "Stresses in Structures." Great suspension bridges, too, are of necessity special problems throughout and must be studied with greater care than any other type.

The floors of railway spans are usually of a standard type, either with steel stringers and ties or else a steel trough floor with ties laid on the ballast; but the types of floor and paving for highway bridges are so numerous that it is often a grave question what to adopt. The cheapest floor that should in any case be used on a good bridge is one having steel joists with spiking strips bolted to them, to which the floor plank is spiked. The very best floor is undoubtedly a reinforced concrete slab, with from 1½ to 2 in. of sheet asphalt surface, although it may be wise to use a creosoted block surface, the thin blocks being set directly in asphalt on the concrete and either filled with sand or grouted.

Having discussed those things which have to do directly with the economy of bridges, with masonry piers and steel superstructures, we may well discuss structures built entirely of stone or concrete, or of reinforced concrete. Such structures must be fully designed and a careful estimate of cost made in order to make any reliable comparisons. The cost of stone bridges is, of course, the greatest of any type that might be considered, and in the case of the Knoxville bridge, where the cost of the arched cantilever was only $250,000, the bid for the stone arch design was about $1,500,000, thus making it out of the question to use stone where low first cost was a necessity. The same is true to a very great degree with concrete arches, but when reinforced concrete arches are considered, they may be designed to cost but slightly more in many instances than steel bridges, and should be carefully considered where a permanent and artistic structure is demanded.

The writer has for many years made a study of the architecture of bridges, and his book of "Engineering Studies" was the first and only attempt that has been made to formulate any rules of architectural bridge design. It will be superfluous perhaps to say that the statement of an eminent engineer, in a recent report on a great bridge, that beauty could not be secured unless economy was sacrificed, does not meet with agreement from the writer.

There are, it is true, no orders of architecture for bridges as for buildings, nor is there any classification of styles for particular ages possible, as in the case of building architecture, but basic rules must be observed, whether the design be for a building or for a bridge.

Simplicity, harmony, symmetry, and proportion must be regarded in any design that would have any pretentions to beauty or to architectural effect. They are the fundamentals of true architecture, no matter what the structure may be to which thought is to be applied in its design.

Simplicity means first a truth-telling structure, no subterfuges about the lines of stress, no covering up of a concrete structure with a stone facing, no frivolous or inappropriate details, but a strict adherence to the necessary features, whether they are to carry the loads or to ornament the bridge.

Harmony is essential to a pleasing design, for without it the structure would be distasteful. Harmony not only as between substructure and superstructure, between the various spans, between the spans and the ap-