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The Economics of Quality in the Fabrication of Welded Steel Bridges

Economie et qualité dans la fabrication des ponts métalliques soudés

Die Wirtschaftlichkeit der Ausführungsqualität bei geschweißten Stahlbrücken

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Preamble

Quality in the fabrication of a welded steel bridge is, for the purpose of this paper, defined as that degree of excellence in the methods and skills employed in fabrication, as will enable the designer to make correspondingly good use of all materials which he may include in such a structure.

The total cost of a fabricated bridge delivered from the maker's yard is the sum of the cost of materials and the cost of production. The better the quality of fabrication, the greater is the cost of production. However, this extra cost is offset by the more efficient stressing of materials, their more economic use, and hence a saving in their cost. The converse is also true. The least total cost will occur where the rate of decrease of one cost, materials or production, equals the rate of increase of the other.

There is very little cost data available, either as to the variation in cost of production or to the variation in cost of materials, due to changes in the requirements of specifications. This paper attempts to show not only the need and the potential value of such data, but also to indicate the relative importance of the factors which cause such variations, and in some cases to make quantitative estimates of the changes in cost.

The difficulty of obtaining data is aggravated by the fact that in any one works it is unlikely that very differing standards of quality can be simultaneously maintained. Thus it is likely that fair comparison can only be made between one works and another; this introduces another variant factor.

Design

Advances in the techniques of design must go forward hand in hand with advances in the techniques of fabrication. Advances in the one stimulate advances in the other.

Welding, more than any other method of jointing metals such as rivetting or bolting, permits the designer to place his metal where he desires, so as to obtain a more logical and economic stress distribution; it permits him to design monolithic structures which even with conventional elastic design show great material savings. This very freedom given to the designer carries with it the risk that any flaw in fabrication is likely to be the more dangerous.

A common reaction to the realization of this fact by the designer, has been to create awkward redundant details, or to specify too long or excessively heavy welds, rather than to insist on a specification of such rigidity that these precautions against flaws in fabrication are unnecessary. It has been shown that for a single stressing of a weldment, high residual stresses as are likely to be set up by such details, have little appreciable effect; however, where fatigue loading is likely to be encountered, as it is in many railway bridges, the effect is considerable. Such precautions moreover, not only cause an increase in the volume of material employed, but also add very considerably in cost and time in the production process. Further to this, the author would go so far as to say that such precautionary details are in fact deleterious to the ultimate strength of a structure.

An analysis of any particular and accepted design on these lines would be likely to be both invidious and inconclusive. It would seem better to consider one or two common details.

A plate girder is usually designed against bending moment; its requirement to resist shear stresses is often negligible. Should this be so, then the paramount task of the web is to hold the flanges apart so that they may take their stresses in direct tension and compression. In this case, the function of a web stiffener is to stiffen the web! It may be extended to stiffen the compression flanges, but there seems no justification for the weight and size of so many sections employed for this task, nor for the excessive and unreasonable amount of weld metal often used in its connection to the web, nor can it be disputed that the laying of this weld is likely to set up high residual stresses and frequently awkward distortion. This is a simple example, nevertheless it is surprising how many designers are still guilty to some extent.

British Standards for mild steel to B.S.S. 15 which has a minimum yield point of 15.25 tons per sq. inch and a minimum ultimate strength of 28 tons per sq. inch, permit the material to be stressed in direct tension to 9 tons per square inch. A bridge made with this steel and to this specification, can therefore theoretically withstand a load 69% greater than that for which it is designed before the yield point is reached in any portion of the steel, and a much greater load, particularly if the steelwork forms a redundant framework, before collapse occurs. There is therefore scope for raising the allowable working stresses provided the quality of the completed structure can be relied on sufficiently. At present there are certain unknown quantities, in particular, the lack of knowledge of the fundamental behaviour of brittle fracture which limit this reliance. Although much can be done to minimise the risk of such fracture, such as the avoidance of notches, discontinuities, etc., the lack of this fundamental knowledge must necessarily delay savings in the general direction of permitting higher working stresses.

The definition adopted for quality excludes discussion on the appearance of the final bridge. It need only be remarked firstly that such practices as placing stiffeners on one side only of a plate girder web, may in the eyes of some be desirable, but certainly add to the cost, and secondly, that a good design that makes full use of the materials employed, is rarely likely to be æsthetically objectionable.

Basis of Estimation of Relative Costs

The total cost of a fabricated welded bridge may be broken down into the following elements:

a) The cost of steel delivered from the Mills (including waste).
b) The cost of electrodes.
c) The cost of miscellaneous special items such as jigs, and tools.
d) The cost of labour directly employed on fabrication.
e) Overhead costs which are usually expressed as a percentage of d). Firms vary in that labour which is classed as directly employed and that which is booked as overheads but for the purposes of comparison the total of d) and e) can be used.
f) Profit, generally expressed as a percentage of the sum of the items a) to e).

The cost of bearings, protective treatment etc., are excluded from the above cost since the method of their calculation is different and a study of their cost is irrelevant to the main argument.

Examples of the use of such a breakdown of cost are given in the following table. They are chosen to represent bridgework of very differing complexity but fabricated to the same specification.

From this table it can be seen that, should the specification, by being made more rigid, cause an increase of one man hour per ton, then the total cost per ton will increase by 0.79%, 0.63% and 0.53% respectively in the three cases. For the change in specification to have caused an economic gain, then it must have permitted a greater percentage saving in weight.

Since the directly employed labour is by far the greatest variable, it is important to examine how the man hours which make up its cost, are split

Item	Class d) Man Hours per ton		
	40	70	100
	£	£	£
a) Mild Steel to B.S.S. 15	45. 0. 0	45. 0. 0	45. 0. 0
b) Electrodes	1.10. 0	1.15. 0	2. 0. 0
c) Miscellaneous Items	1.10. 0	1.10. 0	1.10. 0
d) Directly employed labour @ 5/-d per man hour.	10. 0. 0	17.10. 0	25. 0. 0
e) Overheads at say 125%	12.10. 0	21.17. 6	31. 5. 0
f) Profit @ say 7 1/2 %	5. 5. 9	6.11. 5	7.17. 1
Total cost per ton	75.15. 9	94. 3.11	112.12. 1

between the various trades. The following table gives the percentages by trades of man hours actually employed on the fabrication of four classes of structure. The trades listed cover 70% of the costs booked in the author's works against item d) above.

Item	Category			
	1	2	3	4
Crop, saw, roll, straighten	5.0	4.5	4.0	5.0
Template	2.0	10.0	2.0	1.5
Plane, gas cut	6.0	6.5	7.0	12.0
Mark and drill	10.5	6.5	4.0	Nil
Plater (or assembler)	23.0	23.5	18.0	21.5
Plater's helper	28.0	29.0	30.0	26.0
Welder	25.5	20.0	35.0	34.0

Category 1 was for a multi-span plate girder road bridge with built up welded cross girders. All site connections were bolted. The specification was of normal severity.

Category 2 was for an all welded arch bridge, with main chords of box section. Individual portions were shop assembled. The specification was very rigid, and required exceptional dimensional accuracy. Site connections were bolted.

Category 3 was for a single span plate girder railway bridge with rolled section cross girders. All butt welds were subject to radiographic inspection.

Category 4 was for a box girder cantilever bridge with a main span of 270′ and side spans of 120′. All butt welds were subject to radiographic inspection. It was site welded.

From this table it can be seen that a variation in the amount of man hours employed on welding is not so great as might be expected. For category 3 even, if we assume a total of 70 man hours per ton in directly employed labour, the welding cost (including associated overheads and profit) was only 10.8% of the total cost. Plating accounted even in this case, to a greater proportion (14.8%) and in the case of category 2 to 19.5%.

Inspection

General

Any requirement laid down by a specification must be capable of precise assessment. Such phrases as "of the best quality", "perfectly straight", "without flaw" etc. are largely meaningless.

The methods of inspection available will therefore dictate the quality of materials and of completed fabrications which may be achieved.

Inspection of Welds

There are two basic non destructive methods of examination of welds, firstly visual and secondly radiographic. With the use of standard radiographs, such as those published by the I. I. W. the latter methods can be used precisely. Inspection by magnetic methods, by dye penetrants, by ultrasonic means etc. all indicate discontinuities under various conditions, but they do not guarantee positive nor quantitative identification of faults and must, therefore, be regarded as tools to be used only in conjunction with radiographic means. Hence the section on welding considers only the standards which can be achieved by the use of either visual or radiographic methods.

The initial cost of installing radiographic equipment with the ancillary developing and viewing facilities is fairly considerable, its actual cost depending on the capacity of the equipment installed. For most Bridgework an X-ray machine of capacity 250 KV. is adequate, particularly if a Gamma ray source is made available in addition.

The running costs, including depreciation, overheads, labour and all materials are relatively small. In the Author's works the cost per ton spread over all welded work fabricated is less than $^1/_4$ % of the total cost. This includes all welders tests.

Inspection of Steel

In welded design plates are usually used in single ply, heavier sections being developed by the use of thicker plates. This is the converse of rivetted design where heavier sections employ several plies. Though there is a saving in workmanship there is an added risk in that discontinuities in thicker plates are not only more likely to occur, but also form a much graver source of fault. Hence the discovery of a fault, such as a lamination, may result in the re-fabrication of a large weldment, and the non-discovery of such a fault may weaken the structure dangerously. It is therefore desirable both on economic and structural grounds to examine steel, particularly plates highly stressed in tension, on receipt from the mills for such discontinuities.

Ultrasonic equipment provides the best means for carrying out this inspection. Experience has shown that such inspection will be adequate if on only a small proportion of the materials in a bridge. In the case of plates, if the last two feet at each end are examined and found to be sound, then the remainder of the plates may be assumed to be sound also. One operator with one machine can, by this method inspect in excess of thirty plates per day including the time for laying out the plates and turning over a proportion.

Dimensional

Welding by its very nature causes stresses in the materials connected and hence distortion. Great accuracy may be required and can be achieved between particular faces and in particular dimensions, latitude should be allowed however in those dimensions which are neither important nor critical.

Responsibility for Quality

Primarily (after the operative himself) responsibility for maintaining the quality of workmanship must rest with the shop foreman. The importance of selecting him is therefore emphasised. The justification for ample time and money spent in training, which should continue after his appointment, lies in this fact. Money spent in this manner has rarely been found to be wasted.

Formal inspection is firstly by the Works Inspectors, secondly by those of the customer. This paper is not concerned with the cost of the latter. The Works Inspector should be responsible to the Works Manager directly, and should have preferably been an apprentice trained craftsman who has risen to a position of executive responsibility by his own ability. He should have therefore a well paid position, an essential corollary because so much depends on him in the search for quality.

Materials

Different steels are considered only insofar as their individual properties alter the cost of fabrication.

For example Mild Steel to B.S.S. 15 is in general a sound welding quality steel. However it is possible within this specification for a steel to be rolled with such a chemical content in respect of sulphur, silicon and manganese that welding is difficult and expensive. On what occasions the extra cost of a steel of the same tensile strength, but with a more closely specified chemical analysis which will preclude such difficulties, is justified can only be known with the aid of statistical data which is not available. Another example is in High Tensile (Weldable Quality) Steel to B.S.S. 968.

The welding of this steel either requires pre-heating or a technique resulting in a very high rate of heat input in relation to the thickness of plates being connected. In this case, however, both the extra cost of the steel and of the extra work in welding can be closely estimated as can the saving in weight gained by the use of a steel of this tensile strength.

Welding

Hand Welding

Even to-day there is a widespread impression that, to require the critical welds on a bridge structure to be made to the standard normally specified on pressure vessels, would be impracticable and would cause a gross increase in cost. In the Author's opinion this is not true and the extra cost may well be saved by the avoidance of cumbersome details and excessive sizes and lengths of welds even without taking account of the higher stresses that may be imposed on the materials by the designer.

The attaining of such standards of welding in the first place in a structural works is difficult; their maintenance is comparatively easy.

Previous to 1956 considerable efforts had been made within the author's works to improve the general standard of welding. They had met with only a modicum of success. At about this time advice was given by an eminent manufacturer of pressure vessels that he did not consider it possible to attain more than a mediocre standard without the constant use of radiographic inspection. On installation of such equipment his view was confirmed. The direct visual proof which welders received of the faults in the welds they had made, had an immediate and decisive effect. For some months the rate of welding decreased by some 35% or more, but after a year or so the decrease in rate became less and settled down at between 18% and 20% of that achieved before radiographic examination was employed. This can largely be explained by the extra care taken in cleaning early runs on multi-run welds since the rate of deposition is directly proportional to the current employed.

Actual figures of deposition rate are difficult to compare, since they are dependent not only on the welder but on the time spent awaiting for a weldment to be moved or rotated, or for chippers to complete cleaning etc. Previous to radiographic methods of inspection being employed, butt welds were made with a deposition rate (by hand) of from 4.2 to 5.5 cubic ins. per welder per hour. Two years after such inspection methods were adopted, work to Lloyds Class I Standard or to the "Black" (or best) Standard in the reference book of radiographs of the I. I. W., were from 3.4 to 4.7 cubic inches per hour per welder.

In 1958 several other contracts have been carried out; though radiographic examination has not been required and allowing for the fact that supervision has been fairly meticulous, it is interesting to find that spot checks by radiographic methods of inspection have shown that only seldom has the standard of welding deteriorated at all from the highest standards. In these cases the deposition rate has varied from 4.3 to 4.7 cubic inches per hour per welder — the deterioration of the rate of welding has therefore only decreased from 12—15% of that achieved before radiographic methods of inspection were adopted.

Two major conclusions may be drawn from these facts, firstly that very high standards of welding do not cause exceptional extra costs due to lower deposition rates; secondly that the requirement of the very best standard of welding makes little difference in cost compared with the requirement of the nearly best standard.

There are other costs incurred when radiographic testing of welds is required.

Extra welding is required on coupon plates. On plate girder bridges as much as 25% extra welding is required over that normally laid in the butts on the flanges. The proportion of the total welding on a bridge that occurs in these butt joints varies largely, and each bridge must be considered individually to obtain a precise measure.

A greater cost however by far is caused by any delay which should be incurred. The delay due to the rather slower rate of deposition of welders is of small consequence, compared with the delay caused by faulty welds which must be cut out and re-laid. Compared with the cost due to this delay, the direct cost of labour and materials is small, since the remainder of operations on such a structure may have to await completion of the repair.

Experience at the Author's works shows that for all but jobs of exceptional difficulty no more than $2\,^1/_2\,^0/_0$ of the radiographs taken should show any fault, and on these no more than a quarter of the weld shown has to be cut out. Re-welding should therefore average below 1%.

Automatic Welding

The major advantages of automatic welding compared with hand welding are:

1. Once the machine is set up, the rate of welding is far greater.
2. Provided the fit up is good and the cleanliness is adequate, great homogeneity of deposited weld metal can be achieved.

3. Distortion is minimised.
4. That with many steels the high rate of heat input will permit the amount of pre-heat required to be reduced or eliminated.

The major disadvantages are:

1. The time required to set up the machine for welding.
2. Its lesser tolerance to faults in fit up to dirt or wet etc.
3. That at present downhand and horizontal/vertical welds are the only positions in which reliable production welding can be achieved.

When the methods of overcoming these disadvantages are considered, it will be seen that they are just those methods which will assist the attainment of higher quality.

Thus any complicated weldment will, if the weldment is not rotated or moved by crane power, require the use of special jigs and manipulators. The use of these will permit a great proportion of any hand welding associated to be done in those positions which assist in permitting the best quality weld metal i.e., horizontal or vertical. The accuracy of fit up and the cleanliness of the prepared surfaces will encourage good and consistent weld profiles and weld metal reasonably free from impurity. The lesser distortion will lessen the amount of residual stress included.

There is therefore a strong case that with efficiently operated and controlled automatic welding, economy and quality go hand in hand.

Relative costs are difficult to estimate since they depend so very largely on factors other than the welding process itself such as the efficiency of organization within the factory and the size of the initial capital outlay on machines, jigs and manipulators. Each case must be tried on its own merit.

In the Author's works it has been found possible in several cases to maintain, over comparatively long periods, an arcing time factor for submerged arc welding machines of over 60%. The use of automatic welding equipment is considered on runs of weld down to below 9 feet in length.

Other Processes

Preparation

Between 65% and 80% of the man hours on directly productive trades in the fabrication of a welded steel bridge, are expended on trades other than welding. As will be shown, welding costs are to a considerable extent determined by the accuracy of fit up, and therefore the importance of the standard of workmanship in considering the economics of quality in fabrication is emphasised.

The key to quality in these other trades is dimensional accuracy, and this in the first instance is controlled by the accuracy of preparation. The labour cost of this preparation is less than 20% of the total, and hence the economic justification of rigid control of this section of the fabrication process can be clearly seen.

If we consider a 60° Vee butt weld with a standard gap of $^1/_{16}''$, then, if the gap due to poor fitting increases to $^1/_8''$, in $^1/_4''$ plate an extra 51% of weld metal must be laid; in $^1/_2''$ plate an extra 24%. Similarly, great increases in the volume of weld metal laid occur with inaccuracies due to poor fit up for other types of welding. Further than this, the author would go so far as to say that in general, automatic welding is not practicable without accurate preparation and fit up.

As greater accuracy in fit up is achieved, so costs in preparation increase, but there is a saving in the time of welders and also platers. There is a point at which economy is achieved, and this should be established for each works.

For most operations in preparation, the accuracy achieved is dependent on the operator rather than the machine employed. An edge planing machine for example, should cut well within $^1/_{32}''$ of straight over the full length of travel; similarly a good burning machine within $^1/_{16}''$. A saw will cut stiffeners well within $^1/_{32}''$ of length. The operator, unless well trained and constantly supervised, will seldom work within these limits. The importance of achieving such standards has been demonstrated, and it is considered the laborious work of training operatives to these standards is well justified. It is not considered however, that the rate of output will seriously be diminished once the standard is set and operatives are accustomed to it.

Those ancillary to assembly and welding

Different firms have very different opinions of the extent of responsibility and skills to be expected of a welder. In the Author's works a manual welder is expected to be able to lay sound welds in any position, and to be sufficiently responsible to adhere strictly to any procedures or instructions given by the technical and planning staff.

This staff must therefore plan in very great detail. Their instructions must not only cover such routine matters as electrode type and size, current to be used etc. but also a large number of other matters if weldments of first class quality are to be produced. It is worth while to consider some of these in more detail.

Production Planning

Frequently it can be shown that the most efficient method of fabricating a structure lies in the employment of special jigs or manipulators. The one structure under consideration may not justify the financial outlay necessary to purchase or make such tools. The planning department must therefore not only estimate what tools can be justified, but also whether future contracts are likely to be undertaken which might again utilise the special tools referred to above.

The studies made in planning should also indicate the problems, both in obtaining quality and in achieving savings in efficient production, which would best justify the expense and effort incurred in research into their solution.

Technical Planning

The process of welding introduces high local temperatures in the parts being joined, and high local stresses are set up with their associated strains. Hence each weldment will require individual study to determine the best procedures to minimise the result of such effects. Questions to be considered will include:

The sequence of assembly and welding.
The pre-set to be employed on flanges to avoid distortion.
The control of camber both in the longitudinal and lateral planes.
The control of shrinkage.
Any corrective treatment.
Any pre-heating required.

The detail work to prepare these instructions cannot reasonably be done on the shop floor, and hence must be the work of the technical and planning staff. Men working on technical planning often have other functions such as progressing and hence it is difficult to establish the actual size of such staffs. Such figures as the author has been able to collect indicate that this staff varies from one to every forty, to one to every eighty men directly employed on fabrication.

Taking the greater staff and assuming that the average salaries of these staff are double those of men directly employed on fabrication, it will be seen this staff has a maximum cost of 5% of the total directly employed labour cost, or 0.93% of the total cost per ton of bridgework requiring 70 man-hours per ton directly employed labour.

Hence it can be clearly seen that the technical and planning staff must be as good as can be obtained, and economies in their employment have no justification.

Shop erection

Shop erection is costly, both in labour and in time, hence it is usually economic to minimise the volume of shop erection as far as possible, provided dimensional accuracy can be maintained.

The amount of shop erection carried out is largely determined firstly by the practice of the particular shop in which fabrication takes place, and secondly by the type of site connection employed.

Site welding has the advantage that its use permits a completely monolithic structure to be achieved. It has the disadvantage that in general the dimensional accuracy obtainable with bolted and rivetted connections cannot be achieved. Proving such structures by shop erection is not easy, since the absence of holes makes the location of individual members difficult. These many difficulties themselves make shop erection more necessary, and amongst other things it will probably reduce the volume of welds to be laid at site.

With turned bolts, all the work must be fully erected and site holes reamed in position.

In grip bolts with clearance holes, it is possible to avoid a proportion of shop erection, though in the Author's works it is considered desirable to shop erect a proportion even of such work. Recent research work into the use of grip bolts indicates it may be possible to achieve the monolithic properties obtained by site welding with the use of these bolts, and if this is so, then a saving in cost may be made without losing any quality.

Conclusions

The nature of bridges, in that the failure of even a part may cause a disaster, is such that a poor standard of workman-ship or materials is not acceptable. It is therefore the degree of excellence that must be established when the economics of quality of fabrication are considered.

There is a paucity of data on the extra costs incurred when rigid requirements are needed and achieved. This paucity is emphasised when it is recognised that so much of the data which is available refers to the costs incurred when such requirements are met for the first time. The whole evidence which has been brought together in this paper indicates that it is the attaining of quality that is costly rather than the maintenance of this quality.

Similarly, it is extremely difficult to make a quantitative estimate of the savings in material that may be achieved due to any particular requirement. This is in part due to the reluctance of so many designers to accept the reliability that can be achieved in the final structure, in that they will add extra reinforcements in stiffeners or weld metal to subdue their fears.

It is clear, nevertheless, that the least total cost of a welded steel bridge will be achieved by the employment of an advanced design which takes account of the highest standards of workmanship and materials which can be obtained at the present time.

Summary

Greater accuracy and the further avoidance of defects in the fabrication of welded steel bridges, enable Engineers to make more refined designs, and hence economies in the weight of steel employed. It is difficult to estimate either the extra cost per ton incurred by more stringent requirements, or the saving in weight and hence the saving in cost which these requirements will permit.

The nature of bridges, in that the failure of even a part may cause a disaster, is such that a poor standard of workmanship or materials is not acceptable. It is therefore the degree of excellence that must be established when the economics of quality of fabrication are considered. The paper indicates that the greatest economy is likely to be achieved where the standards of both materials and workmanship are the highest that can be achieved.

It is shown that to achieve higher standards in the first place is almost always difficult and expensive, but that once achieved, the maintenance of these standards is comparatively simple and cheap, hence the extra cost involved in doing a job for the first time to the higher standards, should not be taken as the criterion of whether a further economy can be made.

Résumé

Une plus grande précision et une plus large élimination des défauts de fabrication des ponts métalliques soudés permettent à l'ingénieur de projeter des ouvrages plus élégants et par cela même d'économiser le poids d'acier employé. Il est difficile d'estimer d'une part les frais supplémentaires provoqués par des exigences toujours croissantes et d'autre part les économies de poids et par conséquent de prix que ces exigences entraînent.

Il est dans la nature des ponts qu'un défaut d'une seule des parties puisse causer un désastre; par conséquent, une mauvaise qualité de la main-d'œuvre ou du matériau est inacceptable. C'est donc le degré de l'exellence qui doit être établi lorsqu'on considère l'influence de la qualité sur l'économie. Ce mémoire montre que la plus grande économie sera probablement atteinte là où tant la qualité du matériau que celle de la main-d'œuvre seront les meilleures que l'on puisse atteindre.

Il est prouvé que pour parvenir à une meilleure qualité, il faudra presque toujours compter en premier lieu avec des difficultés et des frais supplémentaires, mais une fois celle-ci atteinte, son maintien est relativement simple et bon marché; pour cette raison, les frais supplémentaires impliqués dans la première exécution d'un travail de qualité supérieure ne doivent pas être pris comme un critère pour les futures économies pouvant être réalisées.

Zusammenfassung

Die größere Genauigkeit und die weitgehende Ausschaltung von Fabrikationsfehlern bei geschweißten Brückenkonstruktionen ermöglichen dem Ingenieur elegantere Entwürfe und damit Einsparungen am Stahlgewicht. Die zusätzlichen Kosten, die durch die höher geschraubten Anforderungen bedingt sind, wie auch die Kostensenkungen infolge der Gewichtsersparnisse, sind schwierig abzuschätzen.

Es liegt in der Natur des Brückenbaues, daß eine schlechte Qualität der Ausführung sowie des Baustoffes unannehmbar ist, da selbst das Versagen eines einzelnen Teiles eine Katastrophe hervorrufen kann. Wenn man die Wirtschaftlichkeit einer bestimmten Ausführungsqualität untersuchen will, so ist vom Grad der Vollkommenheit der Ausführung auszugehen. Diese Abhandlung deutet nun an, daß die größte Wirtschaftlichkeit wahrscheinlich dann erreicht wird, wenn auch die Qualität von Baustoff und handwerklicher Ausführung ein Optimum darstellt.

Es wird ferner dargelegt, daß bei Einführung eines höheren Standards regelmäßig mit Schwierigkeiten und Mehrkosten zu rechnen ist, daß aber, wenn dieser einmal erreicht ist, dessen Aufrechterhaltung vergleichsweise einfach und billig wird. Deshalb sollten Mehrkosten, die bei der erstmaligen Anwendung neuer Arbeitsmethoden entstehen, nicht als ein Kriterium für die zukünftige Wirtschaftlichkeit betrachtet werden.