Relativity and optimization of aesthetic rules for structures

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Relativity and Optimization of Aesthetic Rules for Structures

Relativité et optimisation des règles concernant l'esthétique des constructions

Relativität und Optimierung der Aesthetik-Regeln für Ingenieurbauten

T.P. TASSIOS
Prof. Dr.
Nat. Techn. University
Athens, Greece

SUMMARY
An attempt is made to "translate" basic theorems of aesthetics into guidelines and rules for the appearence of engineering structures. Some incompatibilities between these rules are stressed and the need for an optimization is made evident. Some levels where such optimization should take place are commented. The paper presents a few examples of bridges.

RESUME
On s'efforce de "traduire" les théorèmes fondamentaux de l'esthétique en directives et règles concernant l'aspect des ouvrages de l'ingénieur. Quelques incompatibilités entre ces règles sont soulignées. La nécessité d'une optimisation est montrée. Quelques niveaux sont indiqués, auxquels cette optimisation doit avoir lieu. La communication présente quelques exemples des ponts.

ZUSAMMENFASSUNG
Der Verfasser versucht, grundlegende Sätze der Aesthetik in Richtlinien und Regeln über das Aussehen von Ingenieurbauten zu übertragen. Gegensätze dieser Regeln werden aufgezeigt, und das Bedürfnis nach einer Optimierung wird angedeutet. Es wird diskutiert, wie diese Optimierung angewendet werden könnte. Die Arbeit zeigt auch Beispiele von Brückenbauten.

P r e a m b l e

This paper is largely based on a Monography, of the same author, entitled "Theoretical attempts for the Aesthetics of Engineering Structures", Hellenic Humanistic Society, Athens, 1980.
The basic statements to which that monography has concluded, are here "liquified" (so to say) into general guide-lines and, subsequently, to possible design rules.
However, it is very important to emphasize right now that all we are dealing-with here is but a vague, insinuative and oversimplified sketch of a very complex and intricate mechanism. Consequently, the final results of our endeavours have to be equally seen with great reservedness. After all, to quote HUISMAN, 1961, "the only criterion of Art is ecstasy"...

1.- G U I D E - L I N E S

To begin-with, under the heading "guide-lines", Table I includes first a translation of the aesthetic theorems (major statements) and principles (minor statements) into some more common expressions.
Here come only few comments related to some of these "translations" connected with the optimisational approach this paper is dealing with:

a) **The functionalistic panacea**

An engineering "product" should express its p u r p o s e; otherwise it would violate the first theorem. It should, therefore, have a clarity of its f u n c t i o n.
On the other hand, function alone does NOT necessarily suffice to dictate every characteristic of the final form; such a wholistic claim would arbitrarily abolish all other theorems and principles of aesthetics. And with a nice "theory" it would possibly lead to ugly structures, unless functional consequences h a p p e n (by coincidence) to fulfill many other aesthetic prerequisits. As this is not always the case, f u n c t i o n a l i s m in Struct. Engineering cannot be retained as an aesthetic panacea.
Nervi's wonderful structures offer possibilities for discussions on statical functionalism. His Wool Factory, Rome 1953, has become famous for its ceiling (Fig. 1): The pattern of its ribs follows the isostatic lines of the principal bending moments, "a design which makes possible strict adherence to the laws of statics, and therefore makes the most efficient use of the materials. The aesthetically satisfying results is a clear reminder of the mysterious affinity to be found between physical laws and our own senses", (NERVI, 1965). A micro-functionalism is set-forth here but with much less success, I am afraid:

- There is an infinity of lines of principal moments; which were the criteria for the selection of exactly <u>three</u> M_t-lines and <u>sixteen</u> M_r-lines?
- The "most efficient use of materials" contradicts in this case the "most economic result": curved ribs are much more expensive than straight line ribs...
- Yet, which was the criterion for the selection of structural height and thickness of the ribs? And why not <u>variable</u> height or thickness, following the variability of moments? Incidently, this was in fact the case (variable thickness) in the rectilinear ribs of the ceiling of the Bologna's Monopoly Warehouse (Fig. 2) of Nervi...

The writer of this paper takes the liberty to suppose that the Engineers have saught, here too, an interesting form based on their indisputable inspiration and the well known rules for modern indus-

Table I: A e s t h e t i c a l features to be O P T I M I Z E D (*) in the specific structures and under the specific circumstances

	BASIC STATEMENTS ON AESTHETICS	Constraints: Physiology	Constraints: Historical environment	Constraints: Education + experience	Constraints: Psychological conditions	Guide lines: Positive statements	Guide lines: Possible negative extremes	Possible design rules (which, nevertheless, should be optimized)
Major	1.- Compatibility of form and substance		+	+	+	• Clarity of function, plus possible message	• Boredom	- Give the appearance of strength and stability (+camber of beams, concave soffit of cantilevers etc) - Display the statical solution - Exhibit function and purpose - Slenderness?
						• Sincerity related to the properties of materials	• Mannerism	- Elimination of the needless elements (i.a. by means of colours) - Display the basic consequences of using specific materials - Avoid unconnected ornaments
	2.- Freedom and variety in the small scale			+		• Diversification-internal antagonism	• Chaotic complexity	- Limitation of the number of direction of lines - Repetitions ("rhythm") - Odd number of bays etc - Use of textures
	Order and unity in the large scale	+			+	• Harmony and whole-seeking organization	• Unpleasant uniformity	- Fittness in environment - Expressive proportions - Transition lines - Unity by means of dynamic lines tending to unify, (not to uniformize) - Optical corrections
Minor	a.- Maximization of "information" or minimization of effort to understand and explain it	+	+	+		• Meaningfulness	• Fatigue feelings	- Point of reference in the environment (without descaling it) - Additional simple symbols
						• Simplicity and clearness	• Monotony	- Underlying contrasts to subline main topic - Simple line boundaries
	b.- Some margins for self-action (for imaginative completion)			+	+	• Elleiptic style	• Feeling of disorder	- Interrupting elements - Local disproportions - Certain blanc spaces

(*) For the space where optimization is to be performed, see § 3.

trial design. The idea of the isostatics has contributed to the creation of order with variety; but when these lines are seen in perspective produce a certain confusion (which does not exist in the solution of Bologna's Warehouse...)
Consequently, "there is not only one true form, as Nervi would seem to claim, nor can the science of statics alone determine an architectural form"(a), (MICHELIS, 1966). In this connection too, it is worth to remind that statics does NOT always lead to a unique form. It suffices to remind the possibilities offered for a heavy simple beam (Fig. 3): You may adopt a concave lower boundary line (adapted to the diagramme of bending moments), or a straight line (if an internal, thus invisible, prestressing is used), or even a convex line in case a shear-sensitive material is used!
Definitely, pure functionalism seems today as another obsolete "scientific imperialism"; the modern complimentarity principle in philosophy of science tends to replace, here too, wholistic oversimplifications by a more modest vision of a multiface-reality.

b) Sincerity related to the properties of materials

This is another understandable translation of the theorem of compatibility; it has been said that the sensitive aesthetic mechanism is destroyed as soon as any fraud or make-up is unveiled. Therefore, it is reasonable not to disguise materials. Instead of it, we have an interest to try to create expressive forms out of the opportunities offered by the specific properties of a new material.
However, a certain indulgence is recommended in this connection: "Sincerity" of materials is one thing and offend the feelings of people is another; of people having not yet learned the new "vocabulary". A couple of examples might be here interesting:

- When bridge construction shifted from stone to steel, it took a very long time to the "public opinion" to be initiated; the non-continuum character of trusses, when compared to stone arches, and the multitude of directions of their rods had produced a mixed feeling of instability and confusion. For the famous (and beautiful, for the standards of today) steel-truss cantilever Bridge at First to Forth (Fig. 4), at Scotland (1880), art critic W. Morris had written: "There never would be an architecture in iron, every improvement in machinery being uglier, until they reach the supremest specimen of all uglines, the Forth Bridge", (INGLIS, 1944).
- After all, Parthenon itself is, partly though, a translation of wood temple into stone...

Finally, the term "sincerity" of a material can not be claimed to be nonequivocal: Reinforced concrete "hides", so to say, its own reinforcements. True, some proposals have been made to "indicate" the presence of steel bars (by painting or by means of mortar rods in relief), but nobody has seriously considered such proposals. Why? What "sincerety" has become in this case? I find this question as an excellent occasion to undermine the general applicability of the guide-lines we are dealing-with here, and to subline (once again) the need for an "optimization of rules". In fact, the display of some hints of reinforcements would really have offered a visual guarantee against the very low tensile strength of R.C., but at what an incredible cost - a visual cost again: A mess of lines at several directions, superimposed to the main lines of the stru-

(a) Besides, from the standpoint of "structural accuracy and economy, the thickness of an arch must increase rapidly towards its springers but the artist may find an arch with constant thickness more appealing with respect to its environment", (TORROJA, 1967).

cture, would certainly produce a confusion; that is to say, in order to respect the rule of "sincerity" we should violate the basic rule of o r d e r...

2.- P O S S I B L E D E S I G N R U L E S

With all restrictions repeatedly mentioned along this paper, rules for a more aesthetic design of civil engineering structures do exist. That the use of these rules cannot necessarily produce a work of Art, is another thing; all the same as the use of rules of grammary and syntax can not necessarily secure the production of a good novel. The preparation of a set of such design rules is already achieved by means of the experience acquired out of the large, aesthetically successful, structures. Such is the case of rules observed and recommended by LEONHARDT, 1967, based i.a. on his personal vast experience as bridge-designer for decades, all over the world. Similar rules are suggested by many specialists-Members of the IABSE Task Group "Aesthetics and Structural Engineering". (See also WENGENROTH, 1971).
The last column of Table I is but an orderly rearrangement of well known rules, presented in c o r r e s p o n d e n c e with each aesthetic statement. In a way, these rules and many others may be systematically engendered by theorems, principles and guide-lines, in a r a t i o n a l way, partly though. Nevertheless, the short comments which follow, may offer empeirical backing to some of these design rules and show their limited value.

a) Appearence of strength and stability

Like the wife of Cesar, structures should not only be strong; they also should give the appearence of their strength. We have repeatedly mentioned the sensitivity of the aesthetic process which can not even start to function if safety is not f e l t, ("primum vivere, deinde philosophare"). Something more: We should spotaneously feel margins of safety as well. With non-perceivable upward curvatures of horizontal straight lines ("showing that they refuse to succumb to bending"), as well as with the decrease of spans near the corners, greek temples "overcome gravity and stand free", (MICHELIS, 1966). Similar visual "corrections" are systematically followed today (cambers etc). It is also appropriate to remind here that in modern bridge construction the diameters of piers' columns are sometimes disproportionately small (Fig. 5). Occasionally these structures are labelled as "not beautiful"; the subconsious feelings of unsafety might be the reason. I consider these feelings as an additional defeat of pure functionalism - since these columns are in fact strong enough, but they do not look so when compared to the impressive dimensions of the superstructure.
To end this paragraph with a more relativistic modesty, we should remind the imposing role of previous mental concepts: "Why is the column of a lamp-post much more massive and strong in shape than a flagpole (Fig. 6) which owing to wind forces has to with-stand a greater bending moment? And yet, just try to change one for the other! ", (TORROJA, 1967). Here again, Strength of Materials is not the decisive element; symbolic reasons might explain the preference: A flagpost should f i g h t and still stand - a symbol of battles where flag used to move ahead.

b) Display the statical solution

Independently of the conclusions of §1.a. against any functionalistic fanatism, the existing aesthetic potentialities of direct "statical" forms have also been made clear: Afterall, a "structural"

form possesses inherent features of a s t r u c t u r e[(b)] i.e. of an articulated whole of interdependent parts they obey a unifying law; consequently, such a form has already some of the aesthetic prerequisits.
Nevertheless, I feel it is my duty to remind here that, as it has been shown in §1.a., there is NOT an "automatic" correlation between statically correct and aesthetically satisfactory form.
The example of the purposeful error of Michelangelo in designing the Saint Peter's cupola should also be mentioned - an error which made necessary the strengthening of stone layers with iron: "Michelangelo knew beforehand that this was the weak point of the stability, but did not hesitate to adhere to this design, (although he did tone down this mechanical defect later)", (TORROJA, 1967).
Conclusion: Here again we will adhere to the rule without pushing to the point of another un-aesthetic formalism.

c) Expressive proportions

Here comes one of the most controversial and vague "rules". In TASSIOS (1980) after having discarded any esoteric power of arithmetic or geometric proportions, the aesthetic potentialities offered by some geometric figures have been theoretically reconfirmed. There are also many experimental (psychological) evidences regarding the pleasant feelings the "golden ratio" may impart to average people.
However, "it is always necessary to guard against too strongly held stereotypes: Supersonic aircraft with long thin fuselages and short tapered wings seemed out of proportion when they first appeared, largely because they were compared with more familiar subsonic types", (MAYALL, 1967).
Besides, proportions are strongly dependent on three-dimensional conditions, like the deformities because of a "wrong" angle of viewing: Compare Fig. 7a and 7b of the same bridge (Paleocastro, Crete) seen from the road or from the valley; who (and from where) is talking about good proportions?
Consequently, we have not succeded to give a concrete meaning to the usual claim for "pleasant" proportions, but we have been possibly able to forward the need for e x p r e s s i v e proportions and to underline the rather relative value of a specific rule for proportions.

3.- O P T I M I Z A T I O N

All aesthetic statements, guide-lines and rules retained in Table I have been set forth under a certain reservedness: They are not always c o m p a t i b l e to each-other; consequently, their hierarchy has to be rebuilt each time.
The task of this writer is reduced to a mere enumeration of some possible l e v e l s where such optimisation should take place:

a) The quality of the observers

"Appreciation of the artistic quality of modern work, demands technical culture on the part of the observer", (TORROJA, 1967). In fact, cultural standards influence the aesthetic choices of people. I have experienced a negative attitude of serious people in front of one of my first prestressed concrete bridges (Arta bridge, Fig. 8) because of its vicinity to an old bridge. "Do they not know anymore to make a nice solid bridge?". I am not sure my answer was convincing: "I am in favour of a purposeful contradiction; the

(b) Here the term is used with its broader philosophic meaning. Structural approach in the visual arts has been studied and forwarded by many contemporary scholars, like G. Kepes and others.

modern linear directeness marks-out the ancient curvilinear exaltation".
To which extent the need for compatibility of purpose (a "statical" purpose in the case of a bridge) and form, will be influenced by such social or historical considerations?
I would also like to add another example of my personal works related to a degree of "incompatibility" of form and purpose: Twenty years ago, I accomodated a large aqueduct (water section 3,5 m^2, total length 400 m) with a viaduct (Fig. 9) in such a common arrangement that does not leave the slightest reminiscences of any "hydraulic" purpose. Here the optimization went in favour of practical reasons...

b) **New materials and time-effects**

A similar incompatibility may be encountered between the need for structural sincerity (or "honesty") and the public opinion. Perception is performed through pre-existing mental schemata: The aesthetic transition from one material to another (§1b and Fig. 4) proved difficult and constitutes, again, a problem of optimization between structural sincerity and the public concept about beauty. The same pre-existing schemata, do they actually allow to appreciate the "beauty" of the newly developed pneumatic structures?

c) **Order versus a "honest" display of statical system**

In §1b we have encountered the need for "optimization or rules", in cases where the display of all structural components might violate the rule of order. Another everyday example of violation of the principle of displaying the statical system is the use of sandwich slabs covering the ribs, in favour of a clear "nice" appearance...

d) **Order and orderlines**

But, this continuous care for "order" cannot be a panacea. For KAHN "by order I do not mean orderlines". And for VENTURI, (1966), "meaning can be enhanced by breaking the order; the exception points up the rule. A building with no "imperfect" part can have no perfect part, because contrast supports meaning". Here again, we have to optimize between two extremes: "order" which satisfies our quest for unity and equilibrium, and "disorder" which, if used in an artful way, may create a "poetic tension in the architectural work" (VENTURI).

I N S T E A D O F E P I L O G U E

A certain rationalisation (i.e. a certain oversimplification) has made possible the drafting of some criteria for expressive appearance of engineering structures. Nevertheless, a certain incompatibility between these criteria has been noticed. Their optimization proved to be a really decisive stage, for which criteria cannot be available anymore; it seems that everything has to be played again within the "mind" of the artist!

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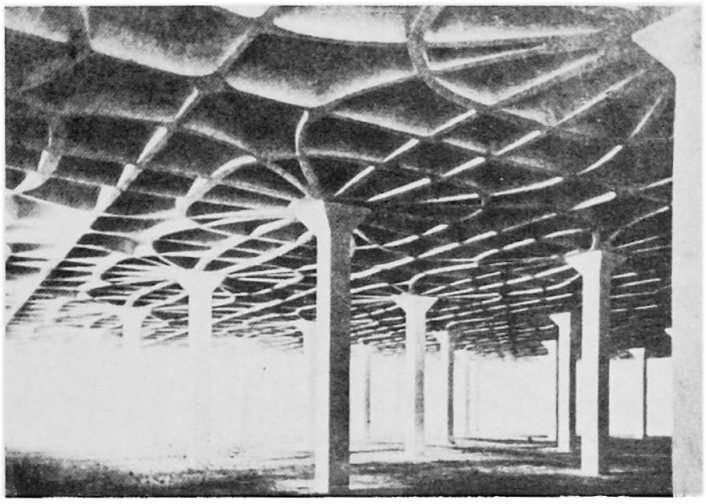


Fig. 1

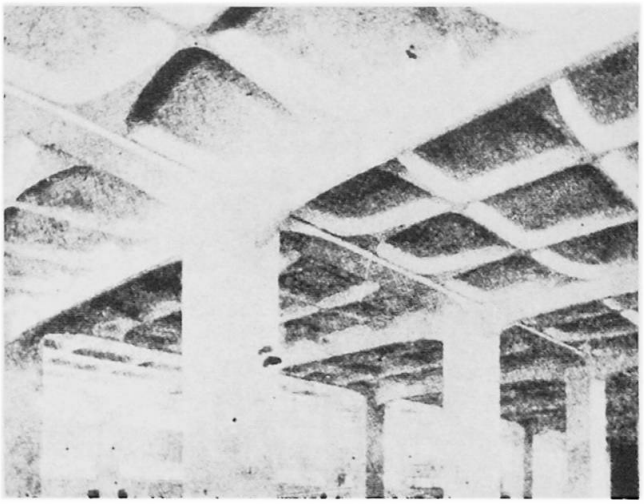


Fig. 2

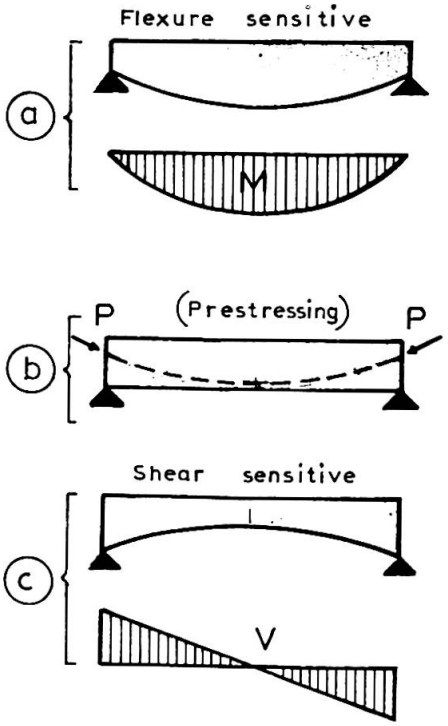


Fig. 3

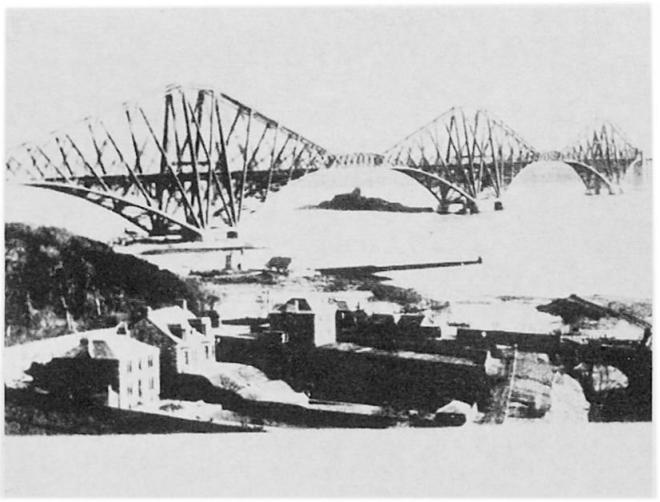


Fig. 4

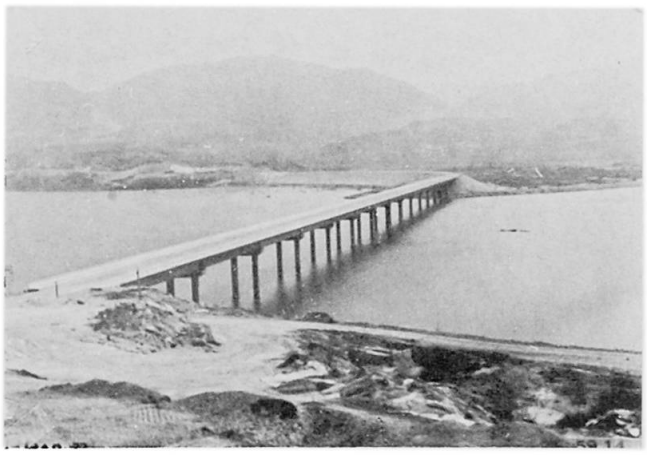
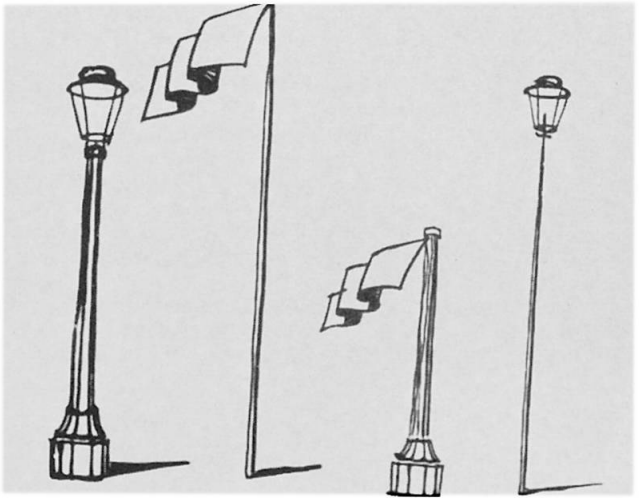


Fig. 5



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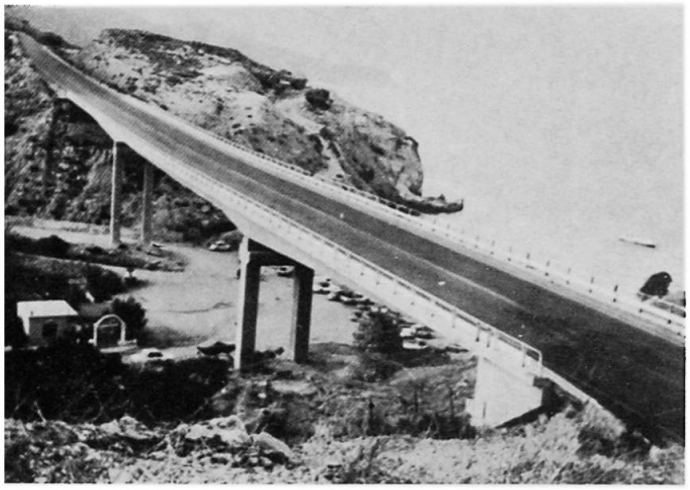

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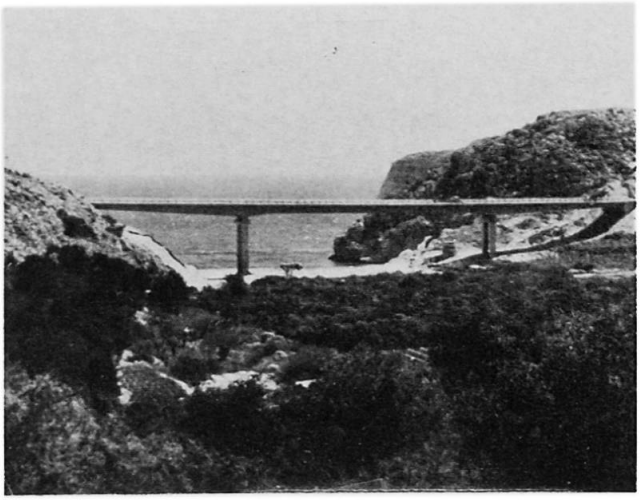

Fig. 7b

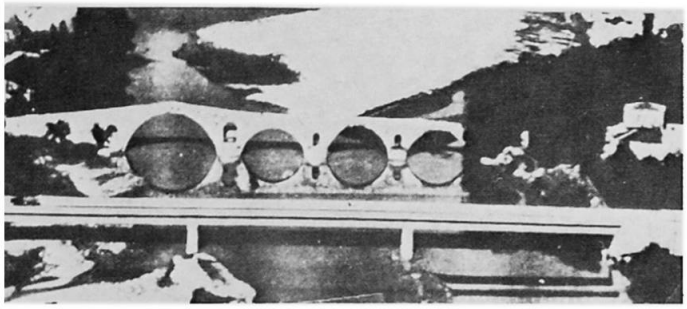

Fig. 8

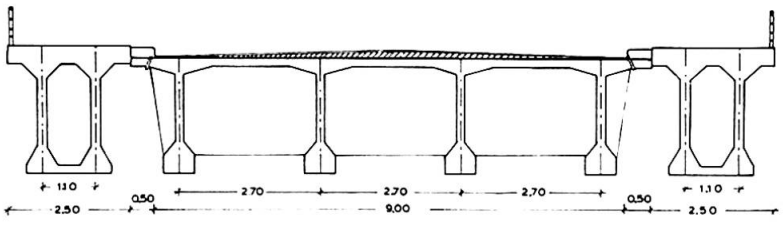

Fig. 9a

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