

Critical Analysis of Consultant's Role in Bridge Design

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Abstract— Skilled and experienced manpower can create wonders in civil engineering, as it facilitates the development of country. This can be achieved by Design consultants who have a major role to play in the construction of civil industries. It may happen, as is generally the case in many fields that some errors do creep in the perception of the consultants while designing structure. The case studies presents the status of situation in design and construction of bridges and also emphasises the need of proof consultant in complicated bridge designs. Some interesting examples of conflicting interests of consultant and client are presented here. The precautions that need to be taken in preserving the interest of client are described in this paper.

Index Terms— designs Criteria, consultants, investigations, safe bearing capacity, authority, well foundation

1 INTRODUCTION

1.1

As per recent census of the total population of 11.23 crore in Maharashtra, 54.77% population reside in rural area and while 45.23% reside in urban area. The highest percentage of population in rural area is found in Gadchiroli (89.00%) followed by Sindhudurg (87.4%). The highest percentage of urban population is found in Mumbai and Thane (76.92%), Nagpur (68.30%) and Pune (60.89%). It is observed that in last decade growth of urban population was 23.7% as against 10.3% in rural. The main objective of road network of state is to cater the needs of this population which is scattered in different parts of the state.

As per the available information, the position of bridges in the state is as under: (Statistics as per the data provided by PWD Govt. of Maharashtra)

Name of Region	No. of Major Bridges	No. of Minor Bridges
Mumbai	435	1536
Pune	385	2342
Nashik	1308	4621
Aurangabad	468	3935
Amravati	266	2631
Nagpur	400	3739
	3262	18804

Thus total number of bridges on state road is 22066 (2014)

1.2

As far as the climatic and geographical conditions are concerned, there is a wide variation in the rainfall of different districts (400-6000 mm) in the state, as well as type of terrain and soil condition in the state. All these factors have great impact on the type of structures to be adopted by the state.

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In Konkan region, there is a large number of creeks, whereas rivers like Godavari, Krishna, Tapi, Wainaganga, Wardha are flowing in other regions of the state. The state government has adopted a policy to serve majority of the population residing in tribal and remote area. At the same time provided facilities like fly-overs, R.O.B. and F.O.Bs in urban area. Thus, there cannot be a unique formula for providing bridge network for state with varied needs of transportation and population.

1.3

As per the policy of the state, different categories of roads are constructed with different permissible interruption criteria in monsoon. So, the various structures adopted are raised causeway, submersible bridge, high level submersible bridge and high level bridge. The cost of these structures depends on the type of structure required to be provided. The state has constructed large no. of flyovers in Mumbai remote areas of Gadchiroli, Bhandara, Melghat, Kinwat and other tribal regions including big structure like Bandra-Worli Sealink along with large no. of bridges on creeks konkan region. The photograph 1 shows the RCC box girder bridge and photograph 2 shows the view of Dahanu creek in konkan.



Photograph 1 MANDAD BRIDGE WITH R C C BOX SUPER STRUCTURE



Photograph 2 DAHANU CREEK BRIDGE

1.4. Present Status of Set Up

The state government has established central design organisation located at Mumbai in 1958. This organisation has completed more than 57 glorious years and is recognised as Class A organisation by M.O.R.T. and H. The officers who have gained experience in this organisation have contributed immensely for development of major bridges in various regions of the state, Bandra-Worli sea link, ROB's and flyovers, eastern freeway in Mumbai and many other parts of the state. In order to serve the requirement of preparation and checking of the design of major bridges, the Design Criteria is prepared by Design Circle. This Design Criteria is a document which defines the various hydraulic & geometric parameters to be considered in the design of bridge. It also gives the deviations from Indian Road Congress codes & Indian Standard codes used for design.

1.5 Procedure of designing bridges

The following procedure is followed by state design organization.

1.5.1 Initially while calling the tenders, the contractor is requested to give the general arrangement drawing (GAD) based on the design criteria given in the tender. One general arrangement drawing prepared by the department is also given to the contractor for reference.

1.5.2 The contractor provides the general arrangement drawing (GAD) along with his price bid. This drawing submitted by contractor is verified by the department and if it is conforming to the design criteria given by department, then the contractor's price bid (a lump sum amount) is considered. Otherwise, the second envelope containing the price bid is not opened.

1.5.3 Once the tender is awarded to the contractor, confirmatory bores are taken by the contractor & geotechnical report is submitted for approval. The various parameters such as safe bearing capacity, foundation reduced levels are approved by competent authority of department.

1.5.4 The contractor thereafter prepares his design & sub-

mits it to the department for approval. The alternate design prepared by the contractor is based on the design parameters approved by the competent authority of department. If the design parameter which is submitted in the design criteria is modified at this stage, then the additional quantities are paid to the contractor as per the rates agreed earlier in the contract.

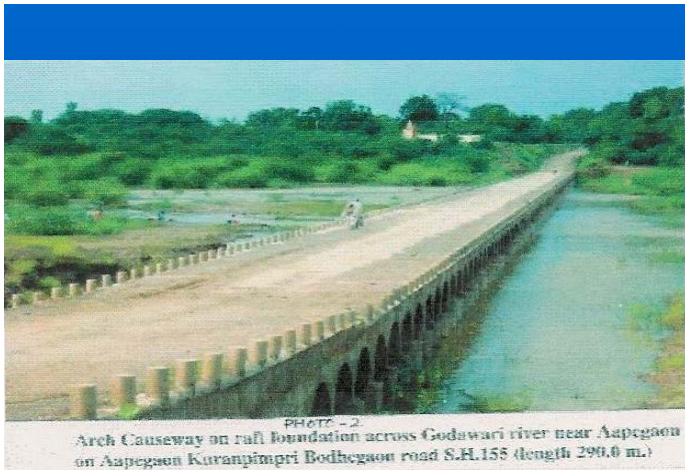
1.5.5 During the execution of contract, the structural designer appointed by the contractor tries to economise the design. But he has to follow the guidelines stipulated in the design criteria. This design criterion, which is the part of contract, is the important document and controls the design features, parameters, governing design of the structure. It defines all controlling parameters such as durability aspects, specifications to be adopted, sight specific properties of parameters needed or design.

After the award of contract, for a design to be economically viable, many a times different methods are used by the design consultant which are not based on sound engineering practice. This leads to conflict of interest with the department/client insisting on completing the work at the cost agreed upon as per contract condition.

1.5.6 The use of the design criteria enables the field officer to avoid variation and claims during contract, while bringing all the contractors on common platform for a competitive bid with regard to the data with regards to the data provided by the department.

This design criteria is constantly updated considering the changes in technology and experience gained by the department. The design criteria is given for each individual bridge depending on the hydraulic requirement of stream and traffic requirement of road. The salient features of present design criteria are as follows:

- a) Higher loading as compared to IRC loading is specified for roads in industrial area.
- b) Different corrosion protection measures are specified for creek structure in coastal area.
- c) Certain provisions are made to specify provisions from different alternatives in relevant I.R.C. codes presently available
- d) The raft foundation which normally is not used by other state in India is also allowed. More than 300 bridges are constructed in Maharashtra. The raft foundation is economical as compared to deep foundation such as well foundation and pile foundation which are being presently used in all other states in India. These bridges are performing well and has given the expected service to the public. A photograph of Arch bridge on length 290 m is shown in photograph 3. So also schematic drawing of such raft foundation bridge is shown in fig 1.



Photograph 3 ARCH CAUSEWAY WITH RAFT FOUNDATION

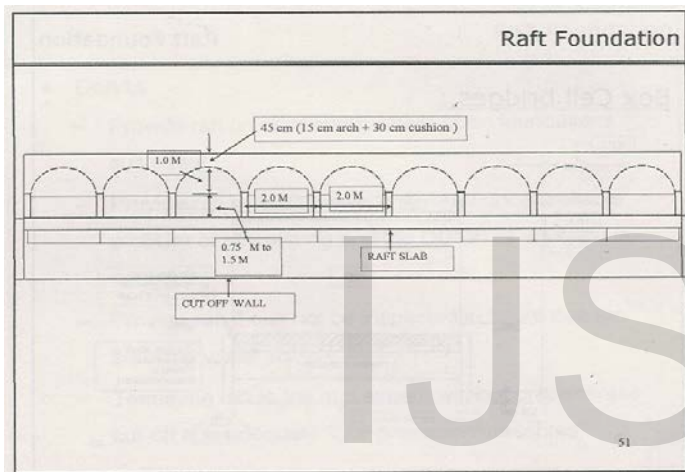


figure 1 SCHEMATIC DRAWING OF ARCH CAUSEWAY WITH RAFT FOUNDATION

e) The hydraulic data for stream is specified as per requirement.

2 SCOPE OF WORK & ROLE OF CONSULTANTS IN DESIGN

2.1

At present lot of problems are faced by client in construction of important structures. Though claim of attractive design is made by the consultants, the cost of these designs is not reasonable and the the number of difficulties are faced by the client's. Therefore the present set up of bridge design and procedure of adopted is reviewed. The roll of consultant in designing of bridges is presented here. After critically reviewing the present set up of bridge design and the roll of consultant from the case studies, the valuable suggestions to improve the results from design of consultant are presented. While presenting the case studies the name of work and consultant are deliberately not mentioned as the intention is to not criticise the consultants but to improve the practice and to get the good results from design of consultant. So also the precaution-

ary measures required to be taken, by client who may be Govt or private individual, are presented here. These suggestions are applicable not only to bridge designs in the state of Maharashtra but all civil engineering structures.

2.1 ROLE OF CONSULTANTS IN DESIGN

The consultant's role is very important in the bridge design. On normal course, proof consultants are employed for checking the design of consultant by private clients while in the Govt. there is a separate organization for checking the designs of consultants.

The scope of the work and methodology to be used for design is defined by the dept./client in the form of design criteria. The consultant has to prepare the design which satisfies the design criteria. The detailed calculations based on design parameters are prepared by consultants and drawings are developed. The dimensions of the structure are decided by drawings of consultants. Thus, the consultant is the pioneer of structure. He may be a structural consultant, geo technical consultant, transportation consultant. The structural consultant analyses the forces resisted by the structure and is responsible for safe design of structure. The geo technical consultant is required to define the soil parameters for designing the structure. The transportation consultant is required for defining the functional requirement of traffic. All these consultants contribute in developing the good design for structure. The structure performs well for desired expected life, only if collective effort of the consultants, results in to attractive, good and safe design of structure.

2.2

During the checking of designs it was observed that, the consultants some time do not plan for the design of entire project at initial stage. This leads to repeated submission of design & results in to uneconomical design. The consultant's opinion changes after the award of contract. The change in the opinion may be genuine in some cases but at sometimes it is intentional to make additional unreasonable claim for the work. If the client is not prudent, then he may have to pay such intelligently fabricated claims. The structural consultant should have knowledge of complete of terms and conditions of contract and also cost induced for his design. If he does not study the conditions of contract, he may have to redesign the work. Also the analysis in structural design needs to be accurate. During design, if the value of forces acting on the structure is incorrectly worked out, there is every likelihood that structure will not perform or even the structure may fail after construction. The consultant has to prepare the design considering the worst combination of forces which may occur during the life of structure. The long term durability is also an issue in designing structure for build, operate and transfer contracts. The experiences in this regard are presented here.

3 CASE STUDY OF VARIATION OF GEOTECHNICAL PROPERTIES

3.1

In case of one creek bridge in Konkan region of the state, dur-

ing investigation it was found that no hard rock is available to rest the well foundation. Detailed investigations were carried out by Geotechnical Engineer & Safe Bearing Capacity of 60 t/m² was recommended for well foundation resting on this strata before award of contract. The span arrangement proposed by department was 2 spans of 52 m., 2 spans of 62 m. and 2 spans of 20 m. (Total 268 m.) The design criteria of the contract mentioned the following clause :

“For departmental drawing, the Safe Bearing Capacity of soil considered is 60 t/m² as per Geotechnical Engineering Consultant’s Report but the contractor’s design shall be based on his own geological investigations and approved by competent authority.”

The geotechnical report was made available to bidders. It was also mentioned that:

“The **contractor** shall take bores by double tube boring machine at final location of each pier and abutment prior to the commencement of work to ascertain the strata levels and its quality at the location of foundation and it shall form the part of contract and shall work out Safe Bearing Capacity and proposed founding level and get the same approved from the Engineer in-charge”.

During pre-bid meeting, one of bidder mentioned that Safe Bearing Capacity varies in direct ratio of area of foundation and also depth. The Safe Bearing Capacity indicated for 8 m. diameter well is 60 t/m². With increase in diameter of well the Safe Bearing Capacity will have to be increased according to some formula. The formula may please be communicated.

The department communicated that Safe Bearing Capacity of 60 t/m² is considered as per geotechnical report independent of diameter and depth of well. It was advised to the field officers to seek the services of another Geotechnical Engineer (consultant) other than the one who had prepared initial report at the time of general arrangement drawing regarding Safe Bearing Capacity.

The lowest bidder proposed 2 spans of 55 m., 2 spans of 59 m. and 2 span of 20 m. It was based on Safe Bearing Capacity of 60 t/m² as per NIT. The Proof Consultant was appointed by department.

3.2 During course of initial geotechnical investigation the consultant of contractor submitted that as per geotechnical investigation done by him, the Safe Bearing Capacity is 50 t/m² and 40 t/m² for P₃, P₄ & P₅ respectively. It was further submitted that due to reduction in safe bearing capacity diameter of well is increased as given below :

For P₃ P₄ pier dia of well = 10.4 m. Safe Bearing Capacity = 50 t/m²

For P₅ pier dia of well = 12.5 m. Safe Bearing Capacity = 40 t/m²

The diameter of well for 60 t/m² as per departmental data required was only 8.32 m.

The contractor’s consultant mentioned that as a result of lower safe bearing capacity, diameter of well is increasing and hence, navigational span may be affected. **Either reduced span will have to be accepted or span of superstructure increased, which would mean variation.** It was proposed to increase the span to **62 m. instead of 59 m.** with the intention to avoid additional payment due to increase in the diameter thereby avoiding undue benefit to the contractor.

But **finally the competent authority sought the second opinion regarding safe bearing capacity and approved Safe Bearing Capacity of 60 t/m².** The contractor mentioned that he is adopting the foundation R.L. and Safe Bearing Capacity certified by competent authority for proposed designs and execution, without any responsibility with him.

As of now the structure is safe while the department is saved from additional claim. This clearly shows that opinion of the consultants differ according to the clients whom they are serving, In such a situation it is imperative that the client should have a second opinion before arriving at any conclusion.

4 CONVENTIONAL WELL FOUNDATION V/S PILE FOUNDATION

4.1

In case of one creek bridge in Konkan region of the state, the field officers specifically insisted on the pile foundation. The details of structure were as under:

Road top level	: 32.5 m. R.L.
Bed R.L.	: 20.5 m.
Scour level	: 17.770 m.
Foundation R.L.	: 1.5 m.

Span arrangement proposed by department was 2 spans of 33 m. with pile foundation. It was earlier argued by the field officers, that pile foundation would remove the uncertainties in completion and work would be completed quickly if the pile foundation is allowed.

4.2

At the time of tendering, the lowest bidder also proposed similar arrangement with pile foundation. But after award of contract the bidder modified the type of foundation and adopted well foundation. But at the time of construction the contractor as well as the field officers preferred **well foundation**. The probable reason was less no. of piles to be constructed and frequency of testing requirements of pile foundation. Since the cost of testing of pile was more, the contractor preferred well foundation. It is on this situation the consultant needs to study the financial aspects of tendering at the time of preparation of general arrangement drawing. It is not adequate to frame the proposal only from structural point of view but also, the feasibility of execution & economy in construction needs to be considered by the consultants. Thus it was the cost of testing the pile foundation which forced the contractor to change his decision.

4.3

However, in case of 'build operate& transfer contracts' the time is the essence of contract. If the contractor completes the work earlier then as per terms of conditions of contract, he can start toll operation earlier and save interest on his investment, resulting in to less project cost. In such cases the pile foundation is preferred by the contractor.

5 CASE STUDY OF INCORRECT ANALYSIS OF STRUCTURE

5.1

In case of another bridge, it was observed that, design of bearings was prepared by the prestigious company in the field of bridge construction. During scrutiny of designs,, it was observed that horizontal force due to **live load breaking** was found to be incorrect at the location of fixed pier. The value reported by consultant was **10.6 t**. The proof consultant, who was reputed one,was appointed by dept. in this case. After submission and checking by proof consultant, it was observed that the **corrected value of horizontal force was 46.5 tonnes**. Due to this corrected value, the diameter of well foundation-was **modified to 7.2 m. from 6.3 m**. If the structure would have been constructed as per the design prepared by consultant and checked by proof consultant it was likely that structure would have failed. This indicates the quality of submission and proof checking by the consultant.

5.2

It is also an observation that some consultants do not submit the worst case which decides the dimension of structure at the time of initial submission and take lot of time for submission of these cases and finally revise their design. During the checking process they also blame the client for delayed approval. Due to such practices the project is delayed or sometimes the approving authority may make mistake of approving unsafe design.

5.3

This scenario explains the need of proof consultant in the construction industry. If the reasonable cost is not known to the client, it is advisable to get second opinion by appointing proof consultant for checking the designs. It is better practice to get the designs prepared by one consultant get checked from another competent consultant, as the designs is a specialized job & one consultant may omit the things which are crucial for the life & better service of structure.

6 CASE STUDY OF INCORRECT SEQUENCE OF SUBMISSION OF DESIGNS

6.1

In case of a bridge in Thane district the length of proposed structure was 380 m. The proposed span arrangement was 4 span of 47.5 m., one span of 45 m, one span of 50 m. and 2 spans of 47.5 m. Hollow circular piers were proposed by the department in GAD. The sections finally adopted by consultant

were as below.



Photograph 4 BRIDGE WITH TALL PIERS
Spanning arrangement: 8 spans of 47.5m
Clear roadwidth+Road+Crash Barrier: 12.75m (2Lane)
Dead Load:1200t
Live Load: 90t

S N	Pier	Ttl ht. of pier	Section	At Height	Steel Adopted	% of steel	Grade of concrete
1	P1	28.38m	3.5X2.0m	15.48	42 No. 25 tor	0.3	M35
			3.5X2.5m	13.48	58 No. 25 tor	0.31	M35
2	P2	32.69	3.5X2.0	17.69	46 No. 25 tor	0.324	M35
			3.5X2.5	16.19	58 No. 25 tor	0.32	M35
3	P3	35.22m	3.5X2.0	20.22	42 No. 25 tor	0.3	M35
			3.5X2.5	18.72	54 No. 25 tor	0.329	M35
4	P4	37.82m	3.5X2.0	22.82	45 No. 25 tor	0.32	M35
			3.5X2.5	21.32	58 No. 25 tor	0.33	M35
			3.5X3.0	10.9	62 No. 25 tor	0.3	M40
5	P5	42.72	3.5X2.0	27.22	45 No. 25 tor	0.32	M35
			3.5X2.5	26.22	58 No. 25 tor	0.33	M35
			3.5X3.0	15.8	64 No. 32 tor	0.39	M40
			3.5X3.5	7.9	80 No. 32 tor	0.53	M40
6	P6	45.81m	3.5X2.0	30.81	45 No. 25 tor	0.32	M35
			3.5X2.5	29.31	58 No. 25 tor	0.33	M35
			3.5X3.0	12.5	64 No. 32 tor	0.39	M40
			3.5X3.5	11	80 No. 32 tor	0.53	M40
7	P7	25.31	3.5X2.0m	10.91	42 No. 25 tor	0.3	M35
			3.5X2.5m	9.41	58 No. 25 tor	0.31	M35

The consultant initially submitted the design of pier P1,P7

(height =28.38m), then the the design of pier P2, P3 (height=35.22) was submitted. The grade of concrete was modified to M40 for P4 for bottom 10.9 m section to limit the stresses in concrete. Then design of highest pier 45.81 m was submitted. The grade of concrete was modified to M40 for bottom 23.5 m. It is an observation that sequence of submission of design was reverse. The consultant tried to limit the concrete section to reduce the seismic coefficient. In the process very slender sections were adopted. Had the pier with highest height been designed initially by keeping the required section with M35 concrete **with minimum steel (0.3%) and then the sections for lower height of pier been designed, a better design was possible.** It is also felt that there should be some practical limits for slenderness ratio to be adopted. The photograph 4 and 5 shows the piers of this bridge.



PHOTOGRAPH 5 PIER OF BRIDGE IN THANE DISTRICT

7 CASE STUDY OF BUILD OPERATE AND TRANSFER CONTRACT

7.1

In case of build operate & transfer project of 4 bridges, the decision of finalisation of hydraulic parameters was left to consultant of entrepreneur.

The controlling hydraulic parameter were decided by consultant of B O T contract. The B O T operator had not carried out any detailed hydraulic calculation of individual bridge but he used the velocity for design of bridges on 4 streams as 4.07 m /sec. These streams were having the different hydraulic characteristics. But in order to save the time all parameter adopted for all 4 bridges were same though the bridges were located at different locations far away from each other.

7.2

So also, consultant considered the value of internal friction as 45° without any testing or approval from client

and section of abutment was decided accordingly. The Abutments were constructed. At latter stage on scrutiny, consultant agreed that he was not aware of local conditions. The height of abutment was 13 m. and the abutment was constructed before the design was submitted to design office. The Proof Consultant also approved designs. Now, the consultant after construction agreed the redesigning the section of abutment for correct value of angle of internal friction and suggested the strengthening of abutments. The consultants submitted design were safe but the factor of safety was much less than specified by IRC specification. The performance of such structures long term is not assured. Such structures would require higher maintenance cost in service.

7.3

It was also observed that the provisions of cables for future pre-stressing as provided in the design criteria was not done. The dimension obligatory in design criteria was also not followed.

7.4

Thus in general, long term durability considerations should be taken care of in B.O.T. projects. The quality should not be ignored because the projects are taken over by client after recovery of toll, at later stage.

8 RESULTS AND DISCUSSION

8.1

The geotechnical investigation before award of contract forms the basis of design criteria which is the part of contract. Normally geotechnical parameters at site does not differ after award of contract as there is only time lag of 4 to 5 months between initial investigation and detailed investigation after award of contract. But for submission of unreasonable claims, these values are modified by consultant after the award of contract. The client needs to be very careful in such cases.

8.2

In case of bridges with pile foundation, the cost of testing of pile foundation is distributed among the number of piles.. If the number of piles is more, then cost of testing per pile works out to be less. For small structures say up to 100m percentage cost of mobilisation of machinery and initial load test of pile may be more as compared to long bridge. However there is no uncertainty in execution of foundations of pile as compared to well foundation. For Build Operate & transfer contracts the time element being important the pile foundations shall be preferred Thus the consultant should study the terms of contracts before actually designing the structure.

8.3

In case of incorrect assessment of calculation of forces on the structure, the structure may be unstable if there is gross error. The analysis of forces & their combination shall represent actual worst case which may occur during the life of structure.. Though, the combination of forces is defined by IRC, due to lack of experience or to avoid calculations, all cases of combinations are not submitted by the consultants of bridges. Some-

times the critical case which decides the dimension is not submitted initially. At later stage, during scrutiny, when it is realized that the critical case is not submitted the drawings are modified. The contractor may have to alter the form work in such cases. There is loss of time due to such submission of design in stages.

8.4

The design work of bridge needs to be started from whole to the part and not from part to the whole. Some consultant starts design of bridges as per the demand from contractor without studying the entire project and agreement conditions. Such practice leads to large number of repeated calculations, submissions, checking and number of revisions of drawing. If the consultant makes careful study of entire project at initial stage, he can reduce the number of drawings and can complete the design work in short time. The work of construction can also be completed in short time.

8.5

In built operate and transfer contracts, after recovery of toll, the structure is handed over to the client. The normal life span of bridge structure is 60 to 100 years. However the concession period (construction period and recovery period of toll) may be 15 to 25 years. Thereafter the facility is to be maintained by client. Therefore during the design and construction in B O T contracts, the durability aspect of such structure shall be given due importance by client to avoid the higher maintenance cost of structure at later stage.

8.6

Considering the above observations, it is found absolutely necessary to regulate and to improve the policy of preparation and checking of designs of not only bridges but also for other civil engineering structures. Though fee paid to consultant and profit consultant is less as compare to overall cost of project, their roll is very important in deciding the ultimate cost and performance of structures. Due to errors of consultant the project cost may enhance substantially. The present practice of appointments of consultants by contractor needs modification. In this regard following suggestions shall be help to improve the present situation.

- i) The Contract of main consultancy shall be between client and consultant and not between the consultant and contractor. It may be noted that ultimately burden of fee of consultant is borne by client only. But when the fee is paid by contractor, naturally the consultant will protect the interest of contractor and not the client. In the larger public interest the and for better performance of structure it will be better practice to appoint consultant by client only.
- ii) The fee shall be paid by client and not by contractor. It will improve the control of client on the work.
- iii) It is better practice to prepare the panel of approved consultant by client. But for the works to be executed through shall exercise better control on consultant by entering in to agreement which has provisions which shall safeguard his interest.

9.5.7 The client shall take second opinion in case of difference between the opinions of consultant after the award of

public funds the work to consultants shall be awarded by open competition between the consultants on panel, based on conceptual design. The criteria of selection shall give more weightage to quality of consultancy work than minimum cost of consultancy.

iv) The portion of fees of consultancy shall be retained even after the completion of physical work of project, till the defect liability period. This defect liability period shall not be less than three years. This retention money may be in the form of interest bearing securities and shall be returned to consultants after satisfactory performance of structure.

v) The client shall keep the documentation of performance of consultants and project shall be awarded based on satisfactory performance only

vi) Similar to the civil contractor, the consultants shall also be penalised in case of default and shall also be given in the incentives in case of good performance.

9 CONCLUSIONS

9.1

The needs of urban population and rural population are quite different. The designs satisfying needs for both classes are to be taken into consideration.

9.2

The design criteria is prepared for each major bridge and provisions shall be constantly updated with changes in technology.

9.2

For major bridges, contractor's own designs are allowed. Considering the various experiences with consultant, the following suggestions shall improve the design practices

ROLE OF CONSULTANT

9.4.1 A consultant should have detailed study of design criteria before bidding.

9.4.2 The misrepresentation of I.R.C. provisions and design criteria should be avoided.

9.4.3 The consultant shall not submit the unreasonable claims by altering the parameters after award of contract

9.4.4 The critical cases deciding the dimension and magnitude of forces should be worked out correctly by the consultant.

9.4.5 The design of bridges should be carried out from whole to part and not from part to whole.

ROLE OF CLIENT

9.5.7 The client shall treat consultant as separate entity and contract.

9.5.8 The quality of work of consultant shall be given more importance than the cost of consultancy.

9.5.8 The consultant shall be made accountable for his performance by suitable amendments in the contract with him.

9.6 The Co-ordinated efforts of professionals, engineers can help in giving simple economical and innovative solutions for bridges and civil engineering structures.

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