

ECONOMICS OF STEEL BRIDGES V/S CONCRETE BRIDGES:

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In the good olden days, for higher spans, steel girders whether plate girders or triangulated girders were pre-dominantly used. After the advent of pre-stressed concrete, its use in higher span bridges increased tremendously. Main reason behind use of PSC girders is due to its initial economical cost. No doubt, PSC girders are economical in the initial stage of construction, but the same may not be true if we consider the life cycle cost including other factors. In this paper, author is trying to explain the various factors, which are mainly ignored while favouring PSC girders over steel girders.

1. Introduction:

In any infrastructural development of a country, Bridge construction is one of the most important constructions. It is very costly structure as compared to others. Lot of considerations are required in doing the investigation, deciding its configuration, type span and final construction of the bridge. A Bridge properly constructed will serve the cause successfully without any hindrance for a longer period and at the economical cost.

Changes in shape, material, configuration and practice have been a continuous process for safe, expeditious, economical and elegant construction of a bridge. For higher spans, in the olden days, steel girders were predominantly used, whether that was for Railway Bridge or Road Bridge or Rail cum Road Bridge. Technology of pre stressed concrete was developed around 1935. First bridge of pre-stressed concrete was constructed simultaneously in many countries of Europe around 1940. India was not lagging behind in adaptation of this technology. In India, first time, Indian Railways used PSC Girder Bridge in 1949 on Assam Rail Link Project followed by another PSC girder bridge by PWD/ Tamil Nadu. After that, a new era of bridge construction had started. Now, most of the bridges particularly of higher spans are made of pre-stressed concrete.

Adaptation of new technology is always a good thing. In similar fashion, prestressed concrete technology for bridges was not only welcomed but was also adapted in such a way, which seems to be somewhat erroneous. Result is that, everywhere, PSC girder bridges are being adopted without giving consideration to many factors.

Main reasons for not preferring steel girder bridges are:

- ✓ Its initial cost is more.
- ✓ It requires recurring expenditure in painting.

In contrary to that, about PSC girders, it is believed that:

- ✓ PSC girders are cheaper.
- ✓ It does not require any type of maintenance.

No doubt, PSC girder bridges are economical in initial cost, but the same may not be true considering life cycle cost of a PSC girder bridge as compared to that of steel girder bridge. To illustrate the matter, let us examine some of the aspects to visualise about the factual position.

2. Availability of configuration and its repercussion on fixing the rail level:

Leaving about plate girders, which are adapted in Railway bridges upto 30.5m (100 ft) spans, for 30.5 m span and above (it is worth while to point out that for 30.5 m span, standard drawing for plate girder and triangulated girder, both are available), 3 types of shapes are available in steel bridge i.e.

- Ø Deck type of triangulated girder.
- Ø Semi through type of triangulated girder
- Ø Through type of triangulated girder

Adaptation of any of the above mentioned type depends upon the situation. Deck type shape is adopted where HFL is much below the formation level of the approach embankment of a bridge. Semi through and through type of triangulated girders are adapted where HFL is high and as such, deck type of triangulated girder is not possible to provide.

Let us look about the prestressed concrete girder bridge side. Most of the PSC girders are of deck type. Hence, alternative to deck type of triangulated girder bridge is available in PSC Girder Bridge also. Now think about alternative to semi through and through type of steel girder bridges. In case of PSC girders, two alternatives are available, ie either to adapt deck type of PSC girder or to go for special type PSC girders of bow- string configuration. Due to special configuration, bow- string type may not have the same cost advantage as in case of normal shape of PSC -I girders and box girders.

For a time being, overruling the possibility of bow- string girders, now again come to the deck type of alternative. With the standard PSC girders and steel girders, a comparison has been done among the two as per standard plan of RDSO and the same is shown in table No.-1

From table No.-1, it is clear that total height from bed block to rail level in case of the PSC girder bridges (particularly for PSC box girders), are almost matching with that of steel girders for smaller spans i.e. for 12.2m and 18.3m spans. In case, I type of PSC girders are selected, although total height from bed block to rail level will be more as compared to that parameter of the corresponding spans of steel girders. Here, we see that the rail level difference being of 740 mm and 846 mm for 12.2 m and 18.3 m spans respectively. Since the differences are not of appreciable value, hence, the same can be ignored.

As and when the spans are increasing, rail level difference between the PSC girders and the steel girders are increasing tremendously for the same span. Due to increase in rail level, particularly in case of adaptation of PSC girders, height of embankment will have to be raised. Raising of embankment height will cause many complicacies. Let us come to those complicacies and evaluate its repercussion.

Table No.1

Rail level difference in PSC girder and steel girder for different spans.

S. N	Span	PSC girder		Steel girder		Level difference in PSC girder & steel girder
		Type of girder & drawing number.	Total height from bed block to rail level in mm	Type of girder & drawing number	Total height from bed block to rail level in mm	
1.	12.2m (40 ft)	Box Girder B-1533	1780	Welded plate girder B-1528	1730	50mm
2.	12.2m (40 ft)	I -Girder B-1565	2470	Welded plate girder B-1528	1730	740mm
3.	18.3m (60 ft)	Box Girder B-1519	2370	Welded plate girder B-1529	2329	41mm
4.	18.3m (60 ft)	I - Girder BA-10227	3175	Welded plate girder B-1529	2329	846mm
5.	30.5m (100 ft)	Box Girder BA-10222	3050	Riveted triangulated girder BA-11341 Welded triangulated girder BA-11461	1583 1583	1467 mm
6.	45.1m (150 ft)	Box Girder B-1750	4250	Riveted triangulated girder BA-11361 Welded triangulated girder BA-11481	1625 1637	2620 mm (Average)
7.	61.0 m (200 ft)	Box Girder Not standardised	5700 (approx)	Riveted through type of triangulated girder BA-11321	2176	3500 mm (approx)
7.	76.2m (250 ft)	Box Girder Not standardised	7100 (approx)	Riveted BA-11151	2176	4900 mm (approx)
8.	92.0m	Box Girder Not standardised	9500 (Reference taken from JURL project)	Not standardised	2500 (Approx)	7000 mm (Approx)

3. Repercussion of higher rail level in case of PSC girders:

From Table No.1, we have seen that in case of adaptation of PSC girders, rail level will be more than that of steel girders of the same span. For this, we have to raise the embankment height so as to provide the required vertical clearance with reference particular HFL by certain amount as shown in the last column of table No.-1. Raising of embankment by this additional height is with reference to the through type of triangulated steel girder bridges of the same span. Additional raising of embankment will require extra land width, extra earthwork and finally extra energy consumption in climbing of the trains by that much extra height. It is worthwhile to point out that extra energy consumption will be of recurring nature.

For comparison sake, calculation has been done regarding the extra energy consumption in case of PSC girder bridges with reference to steel girder bridges for 4500 tonnes goods train (a standard load configuration of a goods train) and 15 coaches of passenger train. The same is reflected in table No.-2.

Table No.2

Details of extra energy consumption, extra land area required and extra earthwork in case of PSC girder bridges for different spans.

S N	Span in meter	Rail level differ ence in PSC and Steel gird -er in meter	Extra energy consumption and cost				Theoretical extra land area in square meter		Extra earthwork in cubic meter	
			For 4500 tonnes goods train		For 15 coach passenger train		For 1 in 100 gradi -ent	For 1 in 150 gradi -ent	For 1 in 100 gradi -ent	For 1 in 150 gradi -ent
			Ene -rgy in Joule x10 ⁶	Approx imate cost in Rupees	Ene -rgy in Joule x10 ⁶	Appro ximate cost in Rup -ees				
1	30.5	1.47	71.3	79.2	14.3	15.9	6406	9609	19985	29978
2	45.1	2.62	127.1	141.2	25.4	28.2	12624	18936	45571	68357
3	61.0	3.50	169.8	188.7	34.0	37.8	19485	29227	72301	108452
4	76.2	4.90	237.7	264.1	47.5	52.8	28077	42116	129794	194691
5	92.0	7.00	339.6	377.3	67.9	75.4	45990	68985	256435	384653

While calculating the extra energy consumption, theoretical value has been enhanced by 10.0% to accommodate the efficiency factor and additional resistance on account of gradient due to climbing. Further more, cost of electricity has been taken as Rs. 4.0 per unit (the cost taken from the Electrical department, which on an average basis, Railways is paying to the Electricity Boards).

Due to fixing of higher embankment height, land requirement and earthwork in the embankment will also be more. Hence, these two parameters have also been worked out and shown in table No.2. Requirement of land width and earthwork is a function of bank height. Hence, for calculation purpose, bank height of 3.0 m, just at the approach of the river bridge has been taken, which can be considered as a representative height in most of the bridges. With this reference, for single line having bank width of 6.85m for PSC sleeper at the top and embankment slope of 2 H to 1 V, extra land requirement and earthwork has been worked out.

3.1 Consequence of extra consumption of energy

Consumption of extra energy in climbing the additional height in case of PSC girder bridges as compared to steel bridges should not only be compared with its cost component. It should be clearly taken in mind that the energy is mostly derived from the fossil fuel, a non-renewable source of energy. Furthermore, extra consumption of energy produces extra pollution in the environment, which is an irreparable damage to the environment.

4. Cost comparison of the steel and PSC girder bridges:

To have a fair comparison among the two, field data has been collected, particularly regarding cost of PSC girders, steel girders, earthwork etc. The same is reproduced as below:

4.1 Cost of PSC girders:

Construction organisation of the Northern Railway has recently accepted the rate of PSC girder bridges of various spans. The same is given in table No.-3:

Table No. 3
Cost of PSC girders:

S N	Span in meter	Per span cost of the PSC box girder including launching	Remarks
1	22.8	Rs. 13.0 lacs	Simply supported span
2	34.0	Rs. 29.0 lacs	Simply supported span
3	45.72	Rs. 50.0 lacs	Simply supported span
4	92.0	Rs. 2.03 lacs per meter run	Rate is on an average basis for continuous PSC box girder having span of 64 m+92 m+64 m.

There are so many factors affecting the cost. On an average, upto 30 m span, cost of PSC girders are coming as 1.2 lacs /running meter including cost of sub structure and super structure. Average cost of 92 m span is coming to Rs.3.86 lacs/m including cost of sub-structure and super structure. Out of Rs. 3.86 lacs/m run, Rs. 1.83 lacs/m run is the cost of substructure and Rs. 2.23 lacs/m run is the cost of super structure

4.2. Cost of steel girders:

Recently, Construction Organisation of the Northern Railway has called for tender for steel girder bridges of various spans. Tender is under finalisation. Rate of the lowest tenderer i.e. of M/s Triveni Structural, Allahabad is given in table No.-4

Table No.4
Cost of steel girders:

S N	Span	Weight per span tonnes	Base price per tonne	Quoted rate above base price	Total rate per tonne including launching
1	80.0m	350	Rs.61000/-	6.5%	Rs.64,965/-
2	102.0m	550	Rs.61000/-	6.5%	Rs.64,965/-
3	154.0m	950 to 1000	Rs.63000/-	6.5%	Rs.67,095/-

The above rate of steel girder bridges are likely to be accepted soon and hence can be taken as a current base price for comparison. Rate of the lowest tenderer is nearer to the base price calculated before calling of tender and hence, seems to be justified.

4.3. Cost comparison:

Based on the data given above, a comparison has been made in-between the cost of steel girder and PSC girder to have a fair idea about its cost. For this comparison, standard Railway span of 45.72m (150 ft) has been selected. This span has been selected purposely since exact rate of PSC girder as well as steel girder both are available for this span. Furthermore, this span is more frequently used as compared to other spans, in case of Railway Bridges, particularly for triangulated girders. Various parameters for these two types of bridges has been worked out and clubbed together for easy comparison as shown in table No.-5

Table No. 5
Traffic requirement to offset the extra cost of steel bridges:

S N	Item	One span	Two spans	Three spans	Four spans	Five spans
1.	Cost of steel bridge in Rupees including channel sleepers with fittings.	7925900	15851800	23777700	31703600	39629500
2	Cost of concrete bridge in Rupees including ballast, PSC sleepers and fittings, extra cost of land and earth work.	8740400	13873500	19006600	24139700	29272800
3	Difference in cost in Rupees.	-814500	1978300	4771100	7563900	10356700
4	10% of difference in cost as interest rate per year in Rupees.	-	197830	477110	756390	1035670
5	Pair of trains (one goods + one passenger) required to offset the amount of interest.	-	3.2	7.7	12.2	16.8
6	Annual Gross Million Tonnes of traffic corresponding to row No.-5		5.26	12.65	20.04	27.59

In the above table, in case of PSC girder bridge, extra cost of land at the rate of Rs. 10 per sq.m. and extra cost of earthwork at the rate of Rs.50 per cubic meter has been taken.

4.4 Comment about initial high cost of steel bridges based on table No. 5:

We have discussed in the introduction part that first and foremost reason behind discarding steel girder bridges are due to its initial high cost. Hence, it is necessary to examine this aspect first

From table No.5, it is clear that for single span, even steel girder is cheaper as compared to PSC Girder Bridge. For two spans and above, position reverses and PSC Girder Bridge becomes cheaper than the steel girder bridge. This is so, since quantity of earthwork and land width will remain the same for multi span bridge or single span bridge. Hence, position reverses for multi span bridge in case of PSC girder and it seems to be cheaper than the steel girder bridge. This aspect is clear from row no.1 & 2 of table No.5.

Vide table No.2; we have already seen that in case of PSC girders one time extra expenditure is there in extra land requirement and extra earthwork. This aspect has already been accounted for in row No.2 of table No.-5.

To work out further, cost difference between steel girder and PSC girder has been worked out in row No.3. This amount can be considered as an extra amount blocked in steel girder bridges at the time of initial construction. Taking 10% as interest rate, in row No.4, interest amount accrued on annual basis for different span has been worked out. In table No. 2, it has already been worked out that for 45.72 m of span, extra cost incurred in counteracting the extra height in case of PSC Girder Bridge for one goods train of 4500 tonnes (standard load configuration of goods train) is Rs.141.2 and for passenger train of 15 coach is Rs. 28.2. Combined extra operational cost of one goods train and one passenger train is coming to Rs. 169.4. For comparison sake, combination of one goods train and one passenger train has been taken as one pair of train.

In row No.5, it has been shown that the per year interest amount on the cost difference is compensated if 3.2 pair of trains on an average basis is operating on daily basis in case of two span bridge. In case of three, four and five spans bridge, numbers of pairs of trains are coming to 7.7, 12.2 and 16.8 respectively. It mean to say that when calculated numbers of pairs trains are in operation on steel girder bridge, then the interest amount of the initial extra expenditure over the PSC girder bridge of the same span will be neutralised. If the pairs of trains are more than the calculated one, then the steel girder bridge will prove cheaper than the same span of PSC Girder Bridge

To have further better idea about the two types of bridges, in row No.-6,corresponding annual Gross Million Tonnes of traffic requirement equivalent to the numbers of goods train shown in row No.-5 has been worked out. Here, passenger trains figure has not been taken into account, since passenger trains are not being counted while calculating the gross million tonnes (GMT) of traffic in railway parlance.

After having a glance from beginning to the end of table No.-5, we come to the conclusion that it is rightly said that:

“ ALL THAT GLITTERS IS NOT GOLD ”.

It means to say that even for multi span PSC Girder Bridge and even initial cost being favorable to PSC girder bridge, in overall scenario, steel girder bridges may be cheaper if we account for the other expenditure like additional operational cost.

In the above calculation, principal amount of cost difference has been kept reserved purposely. We will consider it subsequently.

4.5 Review of recurring painting cost of steel girder bridges:

The second most important disadvantage of the steel girder bridges is said to be about its recurring painting cost. This aspect has also been examined and the details worked out is shown in table No.-6:

Table No. 6

Examination of recurring painting cost

S N	Item	One span	Two spans	Three spans	Four spans	Five spans
1	Difference in cost of steel girder and PSC girder as per table No.5.	- 814500/- (by this amount steel bridge is cheaper at initial stage itself)	1978300/-	4771100/-	7563900/-	10356700/-
2	Present cost of painting (including labour and material.)	66000/-	132000/-	198000/-	264000/-	330000/-
3	Cumulative capitalised cost for 11 numbers of paintings in the life of bridge with 5% interest.	13561680/-	27123360/-	40685040/-	54246720/-	67808400/-
4	Sum of row 1 and 3.	-	29101660/-	45456140/-	61810620/-	78165100/-
5	Scrap steel* after useful life	115 tonnes	230 tonnes	345 tonnes	460 tonnes	575 tonnes
6	Present cost of scrap* @ Rs.8000 per MT.	920000/-	1840000/-	2760000/-	3680000/-	4600000/-
7	Scrap value after 60 years life of the bridge assuming the same escalation i.e. @ 5%.	17185600/-	34371200/-	51556800/-	68742400/-	85928000/-
8	Percentage gain in steel bridge over PSC girder (with reference to row no. 4 & 7)	Already cheaper in the initial stage of construction itself.	18.1%	13.42%	11.21%	9.93%

* Here, scrap value of channel sleepers has not been taken. However, for working out of the initial cost of steel girder bridges, cost of steel channel sleepers has already been taken.

In this table, row No.1 is the same as row No.3 of table No.5 and hence needs no illustration. Row No.2 is the present painting cost including labour and material. For working out row No.3, assuming life of steel bridge as 60 years (as specified in Financial code of the Indian Railways), total 11 number of times paintings will be required. Cumulative cost of all the paintings at the end of 60 years have been worked out assuming escalation @ 5% per annum.

Since annual interest amount of the cost difference of steel girder and PSC girder bridge has already been consumed in compensating extra fuel consumption, so after life of the bridge, only principal amount of the cost difference will be available. Hence, in row No.4, summation of row No.1 and 3 has been done. Row No.5 is the quantity of scrap steel. Its present value is given in row No.6. Assuming escalation @ 5%, scrap value at the end of life of the bridge has been worked out and shown in row No.7. In row No.8, it has been tried to show that steel bridges are cheaper by different percentages varying from 18.1% to 9.93% for 2 span bridges to 5 span bridges.

This table shows that steel bridges are still cheaper. Or, we can here safely conclude that:

“OLD IS STILL GOLD”.

4.6 Effect of interest rate:

On the initial extra expenditure in case of steel bridges, interest rate of 10% has been taken, treating the initial extra expenditure as blocked amount. In near future, rate of interest is likely to decrease. Decrease in interest rate will make the steel bridges more favourable since in that case, even in lesser volume of traffic, steel and concrete bridge will become at par. On painting cost, inflation rate of 5% has been taken on the following consideration:

- ✓ Composite labour and material cost is increasing almost by this rate.
- ✓ Chances are there regarding development of new paints of cheaper variety or of longer life.
- Ø On steel scrap value also, inflation rate of 5% has been taken which is based on past experience and rough estimation.

4.7 Other parameters affecting cost of steel and PSC girders, whose exact amount has not been worked out.

There are so many other items whose cost calculation is difficult but play an important role in selection of a type of bridge. Some of those items are given in table No.-7

Table No.-7
Other factors governing cost of the bridge

S N	Items	Steel Girder	PSC Girder	Remarks
1	Change of bearings	Normally not required during the lifetime of the bridge.	Elastomeric bearings require replacement in 15-20 years and PTFE/POT bearings require replacement in about 20-25 years.	Data is based on the idea taken from manufacturer of the bearings. Here, exact cost of replacement of bearings of PSC girders is difficult to work out due to vague idea of traffic loss, resulting revenue loss
2	Life of the bridge.	Comparatively more.	Comparatively less.	More life of the steel bridge will make it more cost competitive than the PSC girder bridge
3	Inspection	Easy, reliable and worth understanding even to skilled artisans.	Difficult, not so reliable and difficult to understand for skilled artisans	Even field maintenance staffs can easily visualise the health of steel bridge, It is difficult for them to visualise the same for PSC girder bridge
4	Repair and maintenance	Easy to repair and maintain.	Difficult to repair and maintain.	Departmental field maintenance staffs are competent to do the maintenance of the steel bridges, while the same may be difficult for them to maintain PSC girder bridges with the same confidence

All the above factors show positive and favourable indication towards steel girder bridges.

4.8 Cost difference in other spans higher than standard span of 45.72m:

Due to non-availability of exact cost of PSC Girder Bridge in case of higher spans i.e. of 61.0 m and 76.2m of standard Railway spans, precise comparison is not possible. However, a rough estimate has been done for next higher standard span of 61.0m for a two span bridge. Two span bridges has been taken purposely since in the above example, we have seen that even initial cost wise, single span bridge of 45.72m of steel girder is cheaper than that of PSC girder bridge. (After taking extra land and earthwork cost in case of PSC Girder Bridge).

Fabrication, erection including provision of channel sleeper cost of two span of 61.0m steel girder bridge is coming to Rs. 26740200/- (excluding cost of foundation common land and common earthwork cost) Let us assume that the total cost of the bridge of two spans of 61.0 m each of PSC girder and steel girder will be the same. After adjusting the extra cost of land and earthwork, cost of each PSC girder is coming to Rs.10336000/- Without having exact idea of cost of PSC girder of 61.0m span, it is difficult to comment whether per girder cost of PSC girder of Rs.10336000/- is appropriate or not? With this cost, its per meter cost is coming to Rs. 1.69 lacs/ m run.

However, one more exercise has been done for 61.0 m of PSC girder span assuming its cost as Rs.7500000/- (i.e. Rs. 1.23 lacs/ m run). At this cost, cost difference between the steel girder and PSC girder is coming to Rs.5672100/-. In the similar fashion, to offset the interest amount of the cost difference with the extra haulage cost due to additional rise in case of PSC girder, 6.9 pairs of train per day on an average basis will be sufficient.

5. Experience gained from the Konkan Railway:

In India particularly for Railway Bridges, there may not be any other example available regarding most favourably adaptation of PSC girder bridges than that of Konkan Railway. Moto of this Railway was to provide only PSC girder bridges. The author is not commenting about the decision of the Konkan Railway. But one example of that railway is worth quoting, which certainly proves the superiority of steel girder bridges for higher spans and in locations where embankment height is more.

While working out the details on the Zuari Bridge and the Mandovi Bridge, engineers of the Konkan Railway found themselves in a very difficult situation in favouring PSC girders on those two bridges. Main problem was that, from navigational point of view, horizontal clearance of 96 m between the two piers and vertical clearance of 10m from high tide level to bottom of the girder was required to be provided. Nearby road bridge was having span of 124.2 m. Accordingly, it was decided to provide the same waterway in the central portion of the above-mentioned two bridges for navigational purposes.

In the approach of both of the bridges, being coastal area, soil was not having good bearing capacity. As such, height of approach embankment was not possible to raise above 10 m. In case of adaptation of deck type of PSC box girder of 124.2m span to match with the adjacent road bridge, cantilever construction method was requiring a depth of about 12 m of the PSC box girder itself. To accommodate this much depth of PSC box girder and simultaneously to ensure that the height of embankment should not be more than 10m, approach viaducts was required to be extended to the tune of 1500 m. This proposition was not viable at all. In such situation, steel girder bridge came, as savior of the problem where depth from rail level to soffit of the girder was only 1.5m. Accordingly, through girder steel spans were provided on those two bridges in the central portion. On either sides of the central spans, PSC girders were provided of lesser spans, which were of smaller depths and not posing any constraint to the available conditions.

6. Comments on merits and demerits of PSC girder bridges.

6.1 Merits

As we have already mentioned in the introduction part that PSC girder bridges are having so called following two merits:

- ✓ Initial construction cost is less.
- ✓ PSC girders are maintenance free.

Based on the discussion till now, we have seen that initial construction cost of PSC girder bridges is less. But after including operational and life cycle cost, steel girder bridges becomes cheaper than that of PSC girder bridges. Hence, first merit about less initial construction cost has no relevance.

As far as so-called maintenance free aspects of PSC girders are concerned, that does not seems to be justified. Further more, it is too early to say that PSC girder bridges will not require any maintenance. Example of some of the PSC girder bridges reveals that

maintenance is also required for PSC girder bridges. Keeping in view these aspects only, corrosion protection, durability criteria etc came up and now are being followed.

Further more, steel girder bridges are criticized for its regular maintenance, particularly regarding painting aspects. But, normally we forget about the replacement of bearing aspect part in case of PSC girder bridges. In the life of a PSC girder bridge, at least two times bridge bearings will need replacement. Replacement of bearings will not only incur extra expenditure but will also dislocate the traffic. This will further result inconvenience to the public and also cause revenue loss.

One more merit of PSC Girder Bridge is about its facility of providing the same track structure like in approaches. No doubt, this merit is excellent one. But in steel girder bridge, no such disadvantages are there either in shape of speed restriction or any, which may discourage the existing track structure on bridges. In addition, RDSO has standardised and issued many steel girder drawings having ballasted deck. On problematic locations, if any, one can adapt ballasted deck type of steel girders.

6.2 Demerits:

As far as demerits of the PSC girders are concerned, these are-

- ✓ Brittle failure nature.
- ✓ Less life.
- ✓ Very difficult strengthening/repair/ restoration
- ✓ Possibility of tempering of emergency cables by the miscreant in case the same has been provided as a strengthening measure.
- ✓ Changing of bearings problem

6.2.1 Brittle failure nature:

Concrete is brittle in failure. It fails all of a sudden without giving any warning. Failure of Mondovi Bridge at Goa is a burning example. Although, failure of any bridge is not desirable at all but its possibility can only be reduced and cannot be completely eliminated. Where elimination of possibility of failure is not 100%, concept is for ensuring fail-safe mode. In this regard, fail-safe mode of PSC girder cannot be at par with that of steel girder bridges, which is a ductile material and gives lot of warning before failure.

6.2.2 Less life:

Life of PSC Girder Bridge is less as compared to Steel Girder Bridge. Due to less life, its early replacement will be required than that of steel girder bridge. This will require extra expenditure of revenue. Further, it will also cause public inconvenience and revenue loss due to dislocation of traffic at closer intervals.

6.2.3 Very difficult restoration /strengthening/repair process:

In case any repair/maintenance/strengthening of the PSC girder bridge is required due to any reason like deterioration or damage on account of weathering, accident or explosion, the same will not be an easy job at all. Further more, it will be a costly affair also. Even after repair/maintenance/strengthening, field engineer cannot be 100% sure about its complete restoration of the strength.

While in case of steel girder bridges, not only repair and maintenance is easy but also after repair/maintenance/strengthening, field engineer will be 100% sure about restoration of its potential. In case of steel girder bridges, even strength can be increased than the existing strength.

6.2.4 Possibility of tampering of emergency cables:

In case strengthening of PSC girder is required, emergency cables are provided and girders are strengthened. Full possibility is there regarding tampering with the emergency cables in case of PSC girders by the miscreants. This is so since these cables are outside. No such problem is there in case of steel girder bridges.

6.2.5 Changing of bearing problems:

In case of PSC girder bridges, either elastomeric bearings or PTFE/POT bearings are provided. Life of these bearings is much less than the life of PSC Girder Bridge. It means, many times bearings are likely to be replaced in the useful life of PSC Girder Bridge. Changing of bearings is not an easy job. It is not only time consuming and incurring expenditure but also cause dislocation to the traffic.

In contrary to that, in case of steel girder bridges mostly roller-rocker type of bearings is provided. These bearings normally serve upto the useful life of steel girder bridge. This is also an added advantage in case of steel girder bridges.

7. Merits and demerits of steel girder bridges:

7.1 Merits

There are many advantages of steel girder bridges, which is not available in PSC girder bridges. Some of them are listed as below:

7.1.1 Flexibility in strengthening of girders in case of need:

Steel girders provides full flexibility in case its strengthening is required. In this regard, railway bridges of steel girders have proved its ability of flexible nature to get strengthened in case the same is required. Examples of strengthening of steel girder bridges while gauge conversion can be taken. Many of the steel girder bridges, which were found in sound condition except weak in strength for higher standard of loading, were successfully strengthened. Matter has become so popular that on the demand of the zonal railways, RDSO has developed and standardised drawings for such purpose. Details of such drawings are given in table No.-8:

Table No.-8

R.D.S.O Drawings for MG-BG conversion of plate girder bridges

S.N.	Span	Loading Standard	Date of issue	Riveted /Welded	Drawing Number	Remarks
1	9.2 m	Gauge-conversion	18.5.1992	Riveted	B-1639	
2	12.2 m	Gauge-conversion	18.5.1992	Riveted	B-1640	
3	18.3 m	Gauge-conversion	19.5.1992	Riveted	B-1641	
4	24.4 m	Gauge-conversion	18.5.1992	Riveted	B-1642	

With the help of above-mentioned plans, so many meter gauge plate girder bridges had been converted into broad gauge bridges. Thus, Indian Railways has saved huge amount

of money, otherwise new plate girder bridges had been fabricated spending not only money but consuming appreciable time also. This time saving also ensure timely completion of the gauge conversion projects.

7.1.2 About strengthening of triangulated girder steel bridges:

Not only plate girder bridges had been strengthened for gauge conversion projects but even triangulated girder bridges had also been strengthened to make them fit from meter gauge standard to broad gauge standard. Regarding this, example of Izat Bridge over river Ganga, near Allahabad on Allahabad-Varanasi section of North Eastern Railway is worth quoting. Initially, that section of NER was of meter gauge. Under gauge conversion plan, section was required to be converted into broad gauge. Izat bridge was the major constraint. Analysis of the said bridge was done and the design engineers came to conclusion that strengthening of some of the members including widening of the left and right girder will make the bridge fit for broad gauge standard. Accordingly, bridge was modified which saved crores of Rupees, precious time and also helped in completion of the gauge conversion project in time.



Bridge No. 111 of NE Rly. over river Ganga, near Allahabad
This meter gauge bridge was modified into broad gauge bridge while gauge conversion

There might be so many similar other examples also whose details are not readily available to the author.

7.1.3 About re-use of the plate girders and triangulated girders for smaller spans:

Time to time, loading standard on railway was revised as per requirement. Due to revision in loading standard, old bridge had become weak for the same span, even though its condition was good. Instances are there, when such old bridges were removed from the track, new bridges were provided on those locations and the released one were modified to suit for smaller spans and accordingly used.

Such type of flexibility is only available in steel girder bridges. In PSC girder bridges, thinking of such type of possibility is like a dream.

7.1.4 Other modification in the steel girder bridges:

Recent experience of the Northern Railway regarding some other type of modification in steel bridges are very encouraging and worth sharing. For railway electrification work on Saharanpur-Ambala-Ludhiana-Amritsar section of the Northern Railway, CORE (Central Organisation for Railway Electrification) got sanctioned the work without surveying the through girder bridges, whether the required clearances are available in those bridges or not. When officers of the CORE were finalising the detailed drawings, section to section, to their surprise, they found that in most of the important bridges like those on rivers the Yamuna, the Sutlej, the Beas etc, adequate vertical clearances are not available. In such a situation, they approached bridge department. Adequate time for re-girding was not available which otherwise had taken at least five years time even in very tight schedule.

Situation was very difficult for bridge engineers. Even completion plan of some of the bridges were not available, since headquarter of some of the region of the above mentioned section was Lahore, which is now in Pakistan. In such situation, bridge engineers of the Northern Railway accepted the challenge, prepared the drawing as per field data, analysed the bridges for modification work and finalised the drawings. Details of such bridges along with existing vertical clearance and the clearance provided after modification is given in table No.-9:

Table No. –9
Details of modifications of triangulated steel girder bridges

S N	Bridge no.	River	Section	Span in meter	Existing Vertical Clearance in mm	Vertical Clearance provided in mm	Remarks
1	245 combined bridge for UP and DN	The Yamuna	Ambala-Saharan pur	7x61.0	5110	5880	Triangulated girder bridge wide enough to accommodate UP & DN line both
2	251 UP	Western Yamuna Canal	Ambala-Saharan pur	1x61.0	5004	5893	Only UP line required modification
3	283 UP & DN	The Markanda	Ambala-Saharan pur	6x45.72	5020	5520	UP & DN line both bridge required modification involving 12 spans
4	294 UP	TheTangri	Ambala-Saharan pur	3x45.72	5020	5520	Only UP line required modification
5	5A UP & DN	The Satluj	Ludhiana - Amritsar	11 x 61.0	5030	6125	UP & DN line both bridge required modification involving 22 spans
6	20 UP & DN	The East Byne	Ludhiana – Amritsar	4x32.0 Semi-through +2x42.0 Through	4900	5820	Only through spans of UP & DN line (Four spans) required modification
7	63 UP & DN	The Beas	Ludhiana - Amritsar	9 x 61.0	5030	6125	UP & DN line both bridge required modification involving 18 spans

It is worthwhile to point out that modification works on most of the bridges have already been completed except two, which will be taken in hand after completion of the works already in progress.

7.1.5 Easy restoration of traffic after terrorist activities/bomb explosion

There are many examples of the steel girder bridges where after terrorist activities/bomb explosion, bridge was used after strengthening and repair at the earliest possible time. Some examples are given as below:

7.1.5.1 Bridge no.225 over river Markanda on Delhi-Ambala section:

Some terrorists' activity took place about three years back by explosion of some explosive in the bearing area zone of the said bridge. Bridge was having 11 spans of 100 ft. each. Incidence took place on the down line abutment at Ambala end. Bridge girders were under-slung type of duplicate girders. After the explosion, bottom saddle plate cracked, roller of the bearing came out and top saddle plate was hanging. Repair team reached to the site in half an hour. Hard wood packing was provided in the bearing area to support the girder and train service was normalised within two hours time of the explosion. Then after, one released bearing of the old girder bridge was reclaimed and provided in place of the damaged bearing. Some bridge members were also strengthened near the bearing zone by welding MS plates as a mark of Strengthening. As such bridge was restored to the normal strength.

7.1.5.2 Restoration of Hardinge Bridge:

This bridge is over river Ganga in Bangla-Desh. During Indo-Pak war of 1971, Pakistan army exploded the bridge so that Indian army could not proceed further. Due to explosion, one girder fell down in the river. Others were severely damaged. The triangulated girder, which fell down in the riverbed could not be restored. But the bridge engineers of the Indian Railways successfully strengthened other damaged girders. It is worthwhile to point out that after end of the war, Bangla-Desh government took assistance of bridge engineers of the Indian Railways in restoration of that bridge.

Such type of repair and strengthening is only possible with steel bridges.

7.1.6 Easy solution in case of accident/derailment and in keeping reserve stock:

Although, accident/derailment on the bridge portion is having remote possibility, yet the same cannot be ignored. Furthermore, in case of accident/derailment on the bridge portion, due to heavy trainload, chances of damage to the bridge are bound to be there. Again, in such situation, repair/rehabilitation to PSC girder is very difficult and effectiveness of repair is again doubtful. Again, in case of steel bridges repair/rehabilitation is easy as well as of good quality.

In case damage is very severe, and span needs to be replaced, then in case of PSC girder, replacement of the span is very much cumbersome job and likely to take a longer time. In present day situation, closure of bridge for longer time cannot be allowed. It may result huge loss to the national economy.

Reserve stock for steel girder bridge can be maintained and its transportation is also easier. Reserve stock of PSC girder is neither feasible nor easy since the transportation is very difficult.

One burning example of Central Railway is worth mentioning. One of the bridge which was having 14 nos. of spans of 24.4m (80 ft.) each and having pier height of about 18m, met with an accident due to derailment of some of the goods train in 1994. All the 28 girders (up and down line both) of the bridge were affected due to derailment. Keeping in view the quantum of work, Northern Railway bridge staffs were also deputed. It is worthwhile to mention that all the girders were reused after some rectification/strengthening.

If similar incidence has been taken place in case of PSC Girder Bridge, same type of recovery is almost unthinkable.

7.1.7 Restoration of the bridge in case of washing away due to flood and breaches:

Indian Railway is having so many experiences wherein due to flash but welding piers had been washed away resulting this location of the girder. In case of plate girder bridges, girders have been recovered and after construction of a new pier the same has been again put in position.

Details of some of the girder bridges recovered after washing away is given as below. List might be very lengthy. But particulars of those bridges are not known to the author at present.

Table No.-10

Details of steel girder bridges re-used after washing away

S N	River	Section	Bridge No.	Span	Remarks
1	Pamban Viaduct	Mana Madurai-Rameshwaram		105x12.2 m (steel) +40x12.2 m (PSC) +1x61.0 m (steel)	Out of 105 no of spans of plate girder, 104 nos. washed away out of 40 nos. of PSC girders, 19 nos. washed away
2	Local nala	Pathankot-Jammu	196, near Vijay Pur	3x40 ft.	Pier was washed away. Same girders were reused.
3	Local nala	Pathankot-Jammu	216, near Bari Brahman	3x40 ft.	Pier was washed away. Same girders were reused.
4	Local nala	Allahabad-Mughal Sarai	--	1x150 ft.	Under slung girder fell down due to washing away of foundation. The same was reused on new foundation.
5	Patiala-ki-nadi	Rajpura-Dhuri	35, near Patiala	5 x 40 ft.	Due washing away of the foundation, girders fell down and were found about a 200 m. on down stream side. Same girders were reused.

Regarding this experience of Pamban viaduct of the Southern Railway is worth quoting. Pamban viaduct is the bridge connecting Rameswaram with the mainland of the country.

In the night of 22nd/23rd December 1964, one cyclone unprecedented to the history of region came. That cyclone washed away 104 nos. of steel girders of 12.2 m spans (out of total 105 nos.) and 19 nos. of PSC girders out of total 40 nos. The only steel girder, which remained intact, was the Sherzer span, which is a lift span. Probably that a span could not be dislocated due to its heavy weight as well as due to its comparatively stronger fixing arrangement. For restoration of Pamban viaduct, search of girders from South (Kanyakumari) to North (Jalandhar) and from East (Guwahati) to West (Sabarmati) were on. Meanwhile it was tried to recover the dislodged girders from the sea. To the much strange, all the washed away plate girders were successfully recovered, given proper treatment and again placed in the position. Such a massic damage required only 42 days of closure of traffic. Such a glorious achievement was only possible due to steel girder bridge. It is worthwhile to point out that even washed away PSC girders were recouped by new steel girders.

In case of PSC Girder Bridges reuse of the same is not possible at all due to most probably damaging of the same beyond repair and due to further its relaunching problem. In case of steel girder bridge particularly of smaller spans of plate girders, maximum chances are there regarding reuse of the same.

7.1.8 Disposal of the bridge:

After useful life, disposal of PSC girder is very difficult as compared to steel girder. Furthermore steel girder give good return by the way of scrap steel while in case of PSC girder, useful scrap generation is not there.

7.2 Demerits of steel girder bridges:

Steel girder bridges are known for its more initial cost. Mainly this disadvantage covers up its all other advantages. Matter has already been discussed logically how the extra initial cost is being compensated by its so many other associated advantages. It is time to realise the other associated advantages of steel girder bridges which not only nullify the initial extra cost but is also somewhat environment friendly due to spending less consumption of non renewable type of fossil fuels and also its advantages of recycling of the steel itself.

Another disadvantage of the steel girder bridge is about its timely maintenance particularly painting of the same. Painting is not very costly. Furthermore painting also permit cleaning as well as inspection of even difficult part of the bridge location which otherwise is difficult to approach and inspect. There are so many instances when during painting, some of the serious problem in the steel bridge were noticed and then after the problem was rectified.

8. Reuse of steel Railway bridges:

There are so many cases wherein after useful life of the steel bridge in Railway traffic, the same had been handed over to the State Government for using of the same as Road Bridge. Some examples are given as in table No.-11

Table No.-11
Details of Railway bridges now being used as road bridges

S.No.	Section	River & Bridge No.	Year of handing over for using as a road bridge.	Remarks
1	Kanpur-Lucknow	Ganga 110	1910	Bridge is still in use for road vehicles.
2	Near Kalpi	Yamuna		Bridge is still in use for road vehicles.
3	Near Bhuj	Narmada		Bridge is still in use for road vehicles.

9. International opinion about the steel bridges:

Trend about adaptation of PSC girder bridges is now changing. Present international scenario is about adaptation of the steel girder bridges. Change in the trend might be due to most of the facts mentioned in this paper regarding superiority of the steel girder bridges. Unfortunately, in our country, most of the bridges are still being constructed as a PSC girder bridge, without giving in depth consideration to the various factors, some of which has already been mentioned in this paper.

10. Recommendations:

- Ø A thorough study is required before deciding the type of bridge i.e. whether it should be a steel bridge or concrete bridge, to achieve at the appropriate alternative, considering life cycle and operational cost also.
- Ø In case, where bank is high, steel bridge is more preferable.
- Ø In the zone of high traffic, steel bridges should invariably be provided, which will be cheaper than the PSC girder bridge, after considering operational cost.
- Ø In vulnerable location where chances of terrorist activities or washing away of the bridge is expected, steel bridges are more preferable.

11. Conclusion:

PSC girder bridges, which seem to be cheaper than the steel girder bridges on the initial cost of construction basis, may prove even costlier after considering its life cycle cost. Hence, consideration of life cycle cost is more realistic to arrive at the appropriate alternative.

Note:

- i) This paper was published in the Indian Institute of Bridge Engineers Seminar paper held at Mumbai in April, 2002. Although, data about rates are about 3 years old, yet conclusions and other facts derived in the paper still hold good.
- ii) This paper presents views of the author and not views of Ministry of Railways.