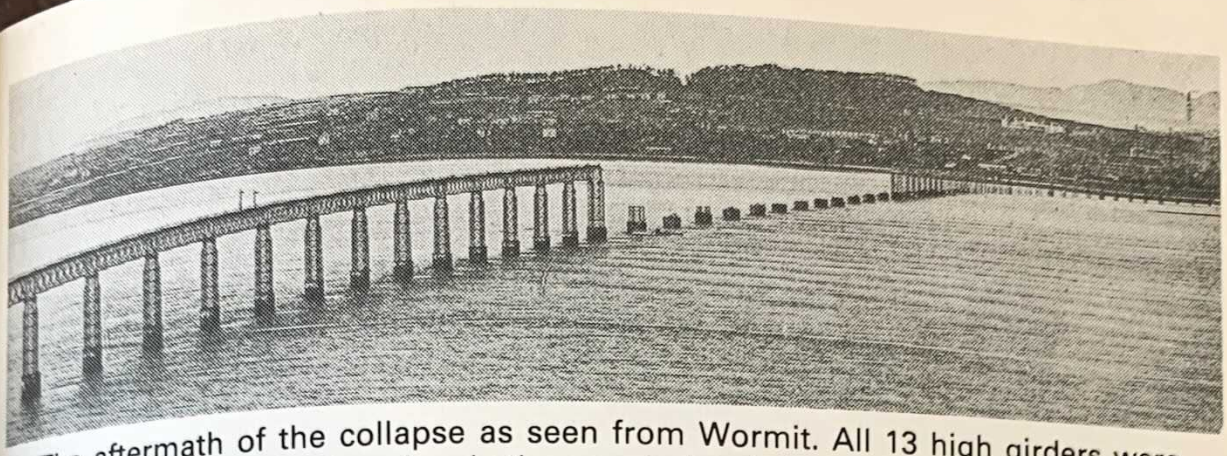


The aftermath of the collapse as seen from Wormit. All 13 high girders were brought down, but miraculously the remainder of the bridge survived. The role in the catastrophe of one of the high navigation spans is explained in the article.

DESTINED FOR DISASTER

Was the first Tay Bridge simply blown down as is popularly believed, or was there some other explanation for this dramatic and appalling tragedy? BILL DOW, retired head of the Science Department at Dundee College of Education, and a leading authority on the subject, has spent many years sifting through the evidence, some of which was not revealed at the Inquiry. Here he explains his theory about the circumstances which caused the collapse.

ONE hundred and ten years ago, at 7.15 p.m. on Sunday 28th December 1879, the 13 high girders of the Tay Railway Bridge crashed into the storm-tossed waters of the river below. At the time, a passenger train from Burntisland was crossing northwards on the last stage of its journey to Dundee. It fell, trapped within the fourth and fifth high girders from Wormit. Although only 46 bodies were identified, it was accepted there had been 75 passengers and crew aboard. There were no survivors.

At the time of the fall, there was a westerly gale estimated by several naval officers at Force 10 or 11. The tide was about halfway out and being helped by the gale.

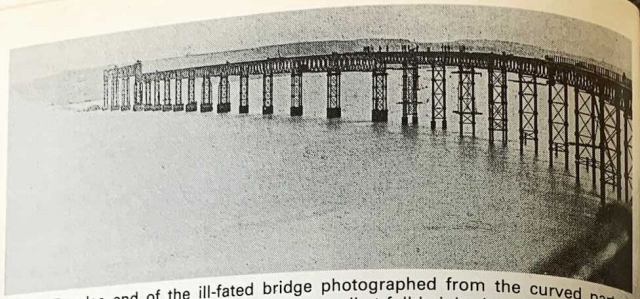
The moon was visible through much broken cloud, but witnesses were generally agreed that at the time of the incident the bridge was in shadow.

Witnesses at Magdalen Green on the Dundee shore watched the train as it set out from Wormit. They could see its carriage windows, although these were lit by low-powered oil lamps. These witnesses knew when the train entered the high girders because the carriage windows began to "flicker" as they passed through the enclosing lattice work, as indeed they still do today on the present bridge.

Witnesses reported seeing flashes on the bridge and three distinct sets of lights cascading into the river. Then all was dark.

Three days later, on the 31st December, the Board of Trade set up a Court of Inquiry. The qualifications of its members were impeccable.

Henry Rothery, Wreck Commissioner, was its chairman. Colonel William Yolland, Chief Inspector of Railways, and William



The Dundee end of the ill-fated bridge photographed from the curved part looking to Fife. High girders 38-41 are now all at full height, but pier 38 is still only partially-built. This picture gives a splendid impression of the fragile appearance brought about when the intended brick piers on the straight part had to be replaced by the cast iron versions seen here.

Barlow, President of the Institute of Civil Engineers were the two members.

A Court of Inquiry is charged with taking all relevant and necessary evidence and with formulating a Report of its findings. This court produced two Reports, one by the chairman and the other by the two engineers. In other words, there was disagreement between the chairman and the two engineers as to what the evidence amounted to.

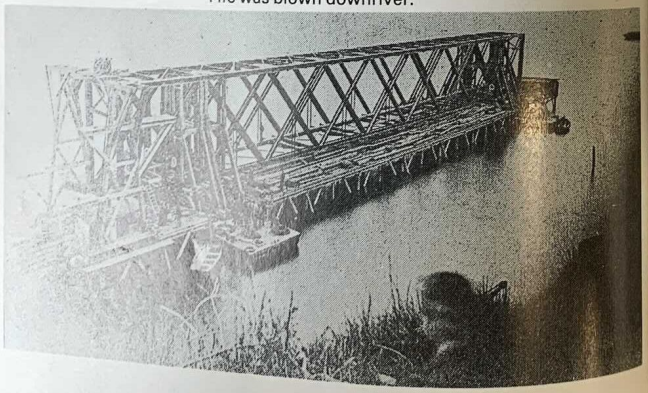
The Board of Trade did not ask the members to form an agreed Report; it simply accepted what it received.

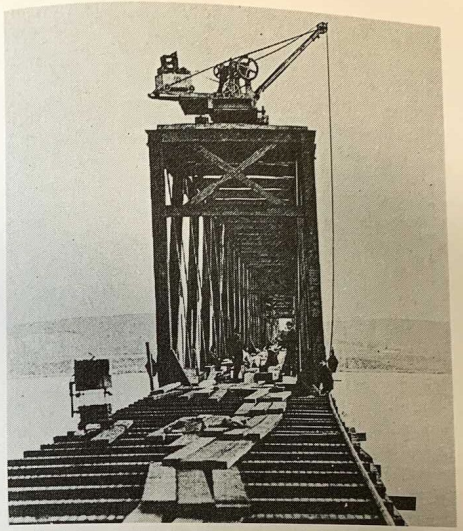
The chairman was quite blunt. He declared that the bridge was badly designed, badly constructed and badly maintained, and that Sir Thomas Bouch (the bridge's designer) was entirely responsible.

The two engineers did not apportion blame to individuals, but detailed their findings impersonally.

Sensing that an injustice had been done and that many more people

The jetty at Wormit with the first of the high girders ready to be floated out on its barges prior to being jacked up to its final position on top of the piers. It was during such a journey from shore to bridge, that the ill-fated high span nearest Fife was blown downriver.





A photograph taken from the top of pier 42 looking south towards pier 41 and the start of the high girders. The wooden planks, possibly those which later formed the deck, are lying on top of the tie bars of low girder 41-42. Bridge designer Thomas Bouch (right) and his manager Albert Groethe are standing at the entrance to the girder.

should have shared the blame, the respected journal *Engineering* published an article, the substance of which was that one day we might know what really had happened. No doubt the writer realised that both Reports gave findings which were not only different from each other, but which totally neglected some of the evidence given at the Inquiry. He may even have suspected there had been a cover-up.

The Tay Bridge Disaster is unique in one respect. In addition to the Minutes of Evidence, the Appendices and the two Reports, we have, by a curious twist of fate, access to the internal private correspondence which passed between the staff of the North British Railway (which operated the bridge) and its lawyers at the Inquiry.

The North British Railway was a privately-owned company and its internal correspondence was strictly its own affair and certainly not for publication. There was no need to preserve it, but somehow the material survived. In 1923 the NBR was absorbed by the LNER, and in 1948 the LNER was absorbed by British Railways.

When the correspondence was in the hands of a nationalised undertaking, it became accessible to the public at large.

I first saw these papers in the office of Mr Hogg, the British Railways Archivist, in Edinburgh in the early 1960s. They have since passed to the Scottish Record Office.

You, too can consult them if you are so inclined.

The surviving correspondence reveals that the Inquiry did not unearth one vital fact. It is doubtful if this could be called a successful cover-up, for it seems to have happened because the Inquiry never asked the right questions.

In essence, the Inquiry failed to find that the high girder nearest Wormit had already been bent several months before the Disaster. This girder was on piers 28 and 29 (the term "pier" that I use describes the tower-like structures supporting the spans).

The history of this span is inextricably bound up with the problems which befell the builders and with the subsequent tragedy.

The original design of the bridge was fundamentally different from what was eventually built. In 1869, Thomas Bouch ordered a survey of the river bed across the proposed path from Wormit on the Fife shore to Buckingham Point on the Dundee side.

The borers declared they had found solid rock all the way across the river just 15 to 20 feet below the sandy bottom. The river is quite shallow, so the bridge could easily be built. It would be the longest bridge in the world.

The initial design was for wrought iron lattice girders supported by solid brick piers on the main straight run of the bridge. The piers north and south of the navigation channel would be placed 130 feet apart; across the navigation channel, the 14 girders would be 215 feet long on piers with centres 216 feet apart. The curve at the north end of the bridge was always intended to be built on cast iron piers.

Had the borers been correct, this bridge would still be standing today. The borers, however, were wrong; for most of the way across the estuary there was no rock at reachable depths. They had mistaken a thin layer of conglomerate for rock — a very serious error indeed.

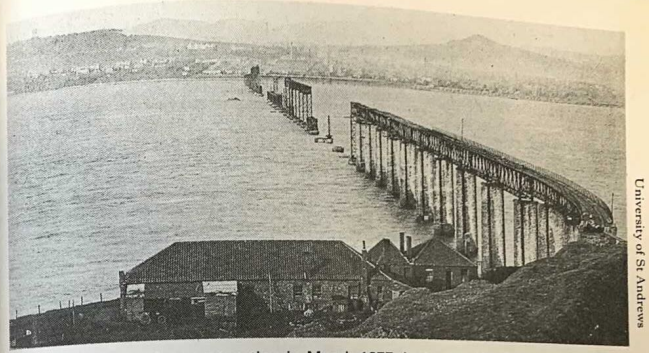
Unaware of the borers' error, building started in 1871 from both ends. The intention was to work out from both shores until the two parts met in the middle. The surviving correspondence suggests that this was done, but photographs show that this plan was soon abandoned.

At the Wormit end, the first 14 piers along with their girders were built to the original plan, but piers 15 and 17 went clean through the "rock" into mud. No foundation could be found.

At the Dundee end, there was trouble right from the start. The curved part should have been built in a few months, but good foundation material could not be located. The curve eventually took four years to complete.

In 1871 my great-grandfather, George McFarlane, stayed at 37 Step Row, Dundee, about 200 yards from the bridge. He was Town Treasurer and had his own small foundry. In addition, he was a personal friend of the Gourlay family who owned the Dundee Foundry. In 1870 the Gourlays had seriously considered tendering for the bridge. Some of the iron work would have been sub-contracted to my great-grandfather who, while still very young, had been Gourlays' foreman boilermaker in the 1840s and 1850s. On seeing the problems with the mud at the Dundee end, they were naturally relieved that they had not become involved.

Because the curved portion was taking so long to build, a start was made late in 1872 with the brick piers of the straight northern part. Foundations were located, but they later gave way. A letter from Bouch to the NBR in 1873 complains that one of the completed brick piers at the north end "keeps going over".



University of St Andrews

The bridge under construction in March 1877, just a month after the fall of the two high girders 28/29 and 29/30. These two spans were at the bottom of the river when this picture was taken, but 28/29 was later to be raised and put back in place. Bill Dow maintains that the use of this damaged span set in motion the events leading to the Disaster of December 1879. This is the critical scene which proves that the bridge was not built out continuously from either bank as surviving correspondence states and other historians have claimed.

The bridge as finally built had no brick piers at the north end.

This letter explained my first mystery concerning the bridge. When I was a student at St Andrews University in the 1940s, I often travelled in the corridors of crowded trains looking at the cut-down stumps of these old piers. At very low tide it was possible to see the remnants of what looked like extra piers about halfway between the true piers. These extra piers had the dumbbell shape of the upper parts of the piers.

In the 1940s these "extra piers" puzzled me. The letter implies that none of the brick piers at the north end had been properly founded. So the two or three brick tops that had been completed must have been stripped off and dumped in the river giving the illusion of extra piers. The surprise is that they sank vertically into the sand instead of falling over.

In 1873/4 the whole bridge was redesigned from pier 14 to the Dundee curve. If there was no natural rock, it would have to be provided. Huge concrete discs, 20 feet thick and some as large as 31 feet in diameter were embedded in the sand below each proposed pier. This was new technology and it was well done. These discs will be there until the next Ice Age scours them out by glacial action. Hexagonal brick cutwaters brought the piers above high tide level. On top of the brickwork the new piers were made of cast iron columns. These were far lighter than the earlier solid brick ones, a precaution observed in view of the absence of a genuine rock foundation.

The Gourlays could have cast these columns in their Dundee foundry and would have made a good job of them. Instead, a special foundry was built at Wormit where all kinds of difficulties were encountered. The columns were frequently badly cast; in particular, essential lugs were sometimes missing.

The discs and the new piers were costly, so the girders were extended to reduce the number of spans required. The piers were 146 feet apart on the southern portion, and

245 feet apart at the navigation channel. Four piers were thus saved, and only 13 high girders were now required in the place of the original 14.

The first four 245-foot girders were placed between piers 37 and 41 at the north side of the navigation channel during April, May, June and July 1876.

The fifth high girder to be put in place was at the extreme south side of the navigation channel. It was on piers 28 and 29, and was the one nearest Wormit.

It is my opinion that this was the girder which set in motion the events which brought about the bridge's downfall. The Inquiry and subsequent researchers apparently failed to realise that a number of stories published during the construction of the bridge all related to this particular girder.

The first of these stories describes its launch. On 23rd August 1876, two barges were placed below its ends at low tide. As the tide came in, the barges rose and lifted the girder off its construction pier — all the girders were taken out by this method. Two tugs began towing it out from Wormit, and almost immediately one of them broke down. There was a strong westerly wind, and despite an incoming tide, the girder was blown downriver almost as far as Broughty Ferry. Another tug came out from Dundee to assist. The girder was towed back and eventually put on its cutwaters at low level late in the evening. Presumably it had been subjected to a fair amount of torsion or strain during its journey.

The second story is as follows. By 2nd February 1877, that very girder and its neighbour on piers 29 and 30 had been rammed up on their newly-constructed piers to just above their final height in the bridge. They were on temporary lifting battens to allow the tops of the piers to be completed below them. Had nothing unforeseen happened, they would have been lowered on to the completed expansion rollers on these piers, but it was not to be.

A sudden fierce westerly gale struck the bridge about 4 p.m. Two gangs of workmen (40 in all) quickly scrambled down on to other 245-foot girders placed at low level on cutwaters 30 to 33. It was as well they did. About 8 p.m., a violent blast blew the two girders and their supporting piers eastwards into the river along with the adjacent 146-foot girder. The girders fell over on to their east sides missing their cutwaters. Their fall stopped when their ends struck the wreckage of the collapsed ironwork of the piers, and their middles bent down to rest on the sandy bottom of the river.

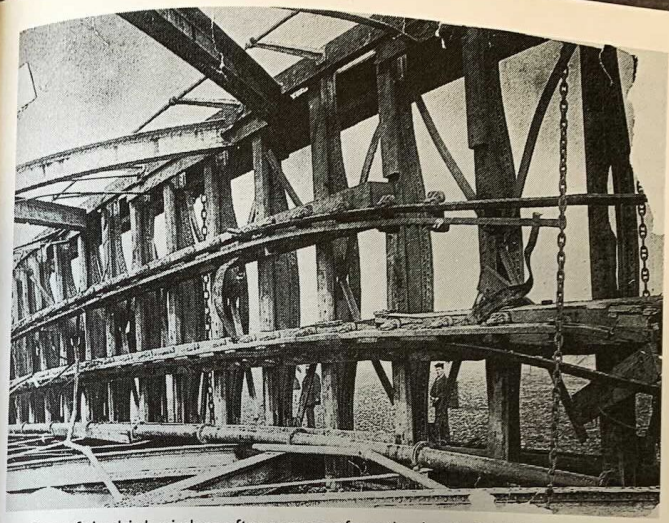
What received less publicity was the comment by the manager Albert Groethe, "One of the two spans was so badly damaged it was left on the bottom. The other was fished out, straightened out and put back up."

Almost two years later, after the bridge was completed, a letter, which is still preserved, was written to Bouch from Henry Noble, the Inspector of the Tay Bridge, it records that he had secretly purchased dynamite from a quarry, smuggled it through Dundee, and used it to blow up the tie bars on the girder still lying in the river alongside piers 29 and 30.

So the girder that was "fished out, straightened out and put back up" was the high girder nearest Wormit. A completely new wrought iron girder was made as a replacement for piers 29 and 30.

On the 25, 26, 27th February 1878, the completed bridge was tested by Major General Hutchinson for the Board of Trade.

Heavy ballast trains and also six heavy tender locomotives coupled together were run many times over the bridge. Indeed, several of the



One of the high girders after recovery from the river bed. It is lying on what was its east side and this photo gives an excellent view of the girder's layout and construction. The longitudinal floor boards have all gone, but the running rails, guard rails, chairs and battens are still in place showing the manner of fixing. As can be seen, if a girder was twisted it follows that the rails would also be out of true. It is this fact that Bill Dow uses to construct his theory about the Disaster.

transits were at speeds of 40 m.p.h.

At that time there could have been nothing apparently wrong with span 28-29 or Hutchinson and his team would have noticed it.

On the 31st May 1878, the bridge was opened for traffic amid great local public rejoicing. My great grand-uncle David McFarlane is recorded as one of the invited guests present at the opening and the subsequent banquet.

Thereafter the bridge settled down to serve its main purpose of providing rapid communication between Fife and Dundee — a task it did with great success.

Twenty months after opening, its 13 high girders collapsed into the river during another gale, but the rest of the bridge remained standing and rode out the rest of the storm even although several of the piers had their cross bracings burst off from their fixing lugs.

When the Court of Inquiry convened early in 1880, its members, along with the lawyers for the Board of Trade and for the NBR, asked all manner of questions and consulted all manner of experts, but they never found out one vital fact revealed in the NBR papers.

The Court summoned the men who looked after the track on the bridge. It summoned the drivers of the trains. It summoned the guards. It summoned the painters.

It asked, "Was the track in good order?" and received the answer that it was. No doubt it was in good order, but nobody asked if the track was straight.

Before their appearance in Court, many of these men had sat in the office of a Dundee lawyer called Thornton. Thornton's notes on these interviews survive and they

reveal that these same men sat and talked about a "kink" in the rails in the high girder nearest Wormit. Their descriptions vary, but there is a common theme throughout.

"The line was just a little out of the straight — a little to the east."

"It was a gentle curve towards the north end of the high girder nearest Wormit."

"You could feel the train go over a little to the east."

"You could see the engines just nod into it."

"It was as if the pier had gone over a little to the east."

"It was nothing very serious. The line was just a little out of the straight."

"It extended over about 60 feet or so."

All the drivers and the platelayers seemed to know of it. The common theme mentioned by them all was that the line in girder 28-29 was bent slightly downwards and to the east.

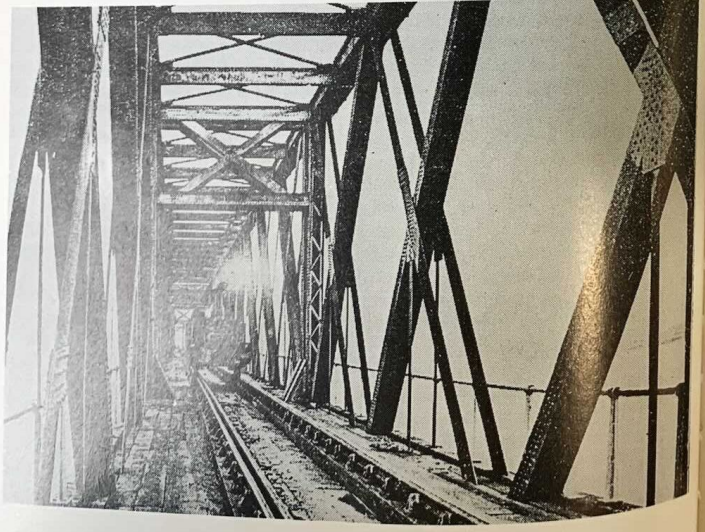
The rails were supported every three feet by very heavy double chairs carrying both a running and a guard rail. These chairs were bolted to long wooden battens parallel to and just below the rails. These battens were themselves bolted directly to the wrought iron tie bars which connected the bottom booms of the main girders. This construction was explained at the Inquiry and is shown in photographs.

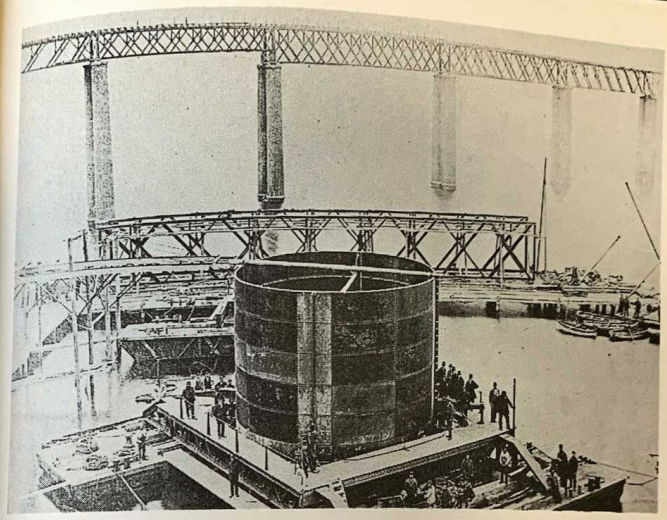
If the rails were depressed and bent eastwards, the girder itself must also have been bent in this fashion.

My opinion is that during the passage of trains over the bridge, this span very gradually deformed towards the distorted shape caused by its fall in February 1877.

For some years now, I have been convinced that when the train passed through this girder on the

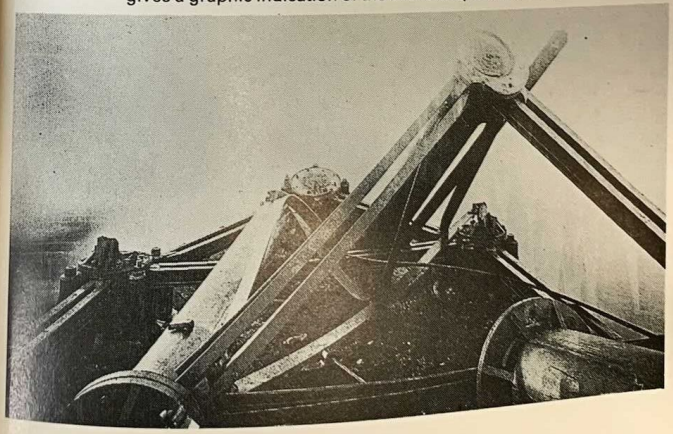
A contractor's locomotive inside one of the high girders approaching the triangular plates at the ends of each of the spans. It was this obstruction at the top of pier 32 that was to take the impact of the derailed carriage and crack the cast iron lugs of the support columns thus setting in motion the collapse of the bridge.

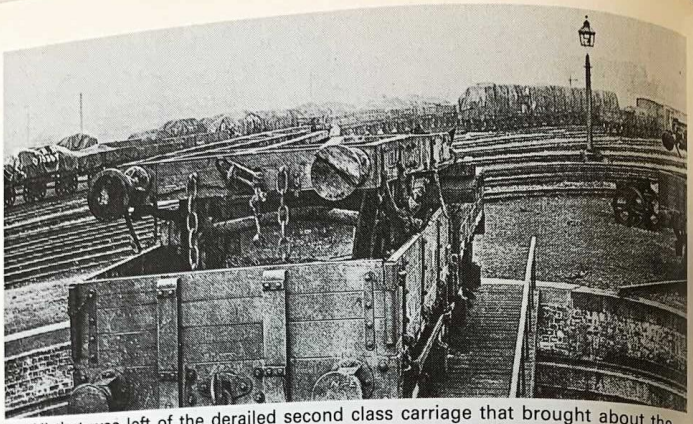




One of the 31-foot diameter caissons on its barges ready to be floated out from Wormit to the middle of the river. This civil engineering innovation was devised by Thomas Bouch expressly for the construction of the first Tay Bridge, a move forced on him by the failure to locate rock on which to found the piers.

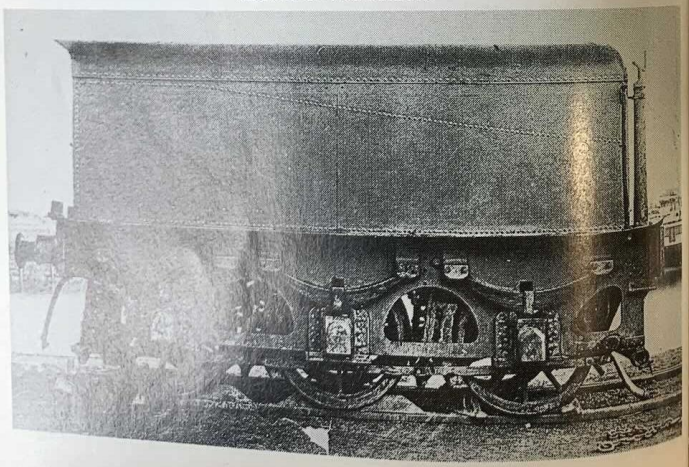
Below, looking west over one of the piers after the Disaster. The cast iron columns are broken from their flanges, but the holding down bolts which fixed the ironwork to the stone tops of the cutwaters are all intact (none of the holding down bolts gave way). At the top of the picture, an end of the wrought iron cross bracing can be seen still intact and still with a bolt through it. None of the ends of the cross bracings were broken by tension or shear. In all cases, the cast iron lugs of the columns snapped off under tension. This tangled and shattered mess gives a graphic indication of the immensity of the collapse.





All that was left of the derailed second class carriage that brought about the bridge's downfall. The chassis is shown here on top of two wagons on the turntable at Dundee. Note the bent axle in common with all the carriage axles on the Disaster train. This damage has never been satisfactorily explained until now, but the writer believes the coaches were all thrown into the air by the whiplash action of the five joined spans immediately after their support piers gave way, and then crashed down at an angle on to the bridge decking on either their east or west wheels. It was this impact which distorted the four-inch thick steel bars that formed the axles. Note, too, the bent sole bar (side frame), distorted when the brake van telescoped into it when the triangular plate was struck.

The tender of the ill-fated locomotive No. 224 at Tayport after recovery. Apart from slight bending of a buffer beam, and loss of paint by tide action, it was undamaged. Inside span 32-33 it had fallen 100 feet into the river and then through about 20 feet of water. The fact that it remained virtually unscathed while the coaches behind all suffered badly, reinforces the author's argument that it was the whiplash action of the bridge in its dying moments that brought about their destruction.



night of the disaster, the engine, tender and first four coaches negotiated the "kink", but the very light fifth vehicle (an old second class coach) jumped the rails assisted by the lifting effect of the westerly gale. Because of the longitudinal battens and flooring, it was towed unobstructed through the next two girders running on the floor. Lamps which could have belonged to it were found below the third girder.

Halfway through the fourth girder, the wind blew this vehicle eastwards so that it scraped along the east girder leaving scores on it and pushing pieces of its wood between cover plates and the main beams. Its bodywork gradually disintegrated as if in a grater as it was dragged along the latticework. Finally it collided with a triangular bracing plate projecting into its path at the end of the fourth girder. The guard's van behind it, still on the rails, struck the coach, telescoping the two vehicles together. The west solebar (chassis member) of the coach was broken and the bodywork of both vehicles smashed.

The rest of the train, still on the rails, had meanwhile passed into the fifth girder. When the second class carriage stopped, it jolted the couplings on the rest of the train and burst them. As soon as this happened, the Westinghouse brake system on the engine and first four coaches operated, bringing the vehicles to rest. *The sudden impact of the derailed coach against the plate plus the bursting of the couplings on the rest of the train was effectively the hammer blow which caused the brittle cast iron lugs to fracture, but left the wrought iron cross bracing almost unaffected.*

With the lugs broken, the cross bracing was useless. The five spans between piers 28 and 33 were riveted together to form one continuous girder fixed securely to pier 31. This pier would have taken much of the blow. Its columns must have begun collapsing gallery by gallery in zig-zag fashion as shown on this month's cover. Deprived of its support, the long girder sagged, pulling adjacent piers out of position and causing them to collapse. It had one final job to do before it went into the river. It had to burst the four rails above pier 28 and above pier 33. I believe its downward path was halted just for a moment as it burst these junctions. The severing would send a pulse or ripple along the five sagging girders in much the same way as a clothes line reacts when plucked. I believe this was sufficient to toss the light carriages, but not the engine and tender, upwards from the rails.

With the wind still blowing, the carriage bodies moved slightly eastwards so that when they fell back, their wheels struck the wooden deck at an angle, bending the four-inch diameter steel axles upwards. The axles of the engine and tender were not bent, indicating they were never off the rails until they were in the river. The deformed coach axles have never been convincingly accounted for by any of the other theories advanced at the Inquiry.

Benjamin Baker explained with great care to the Inquiry that all the evidence of damage to the bridge was of catastrophic failure of cast iron and virtually no damage to the wrought ironwork. For this to happen, a severe blow would be required, but his notion of merely a derailed coach is unconvincing.

Who was Benjamin Baker? Well, he subsequently designed the Forth Bridge. If Baker had talked to Thornton, he would have been able to explain the blow. On the other hand, maybe he had, and was not saying all as he could have done.

When the Inquiry published its two Reports, the writer in *Engineering* must have realised that the main parties had nothing to gain

by revealing just how badly certain parts of the bridge had been built.

The NBR's story was that there was nothing wrong with the bridge. It had required an exceptional gale plus a derailed train to bring down part of it.

Less than two years before the collapse, the Board of Trade inspectors had passed the bridge fit for all traffic subject to a speed restriction. Each revelation of bad workmanship simply served to ridicule its own inspectors.

Even the engineers, both those on the Inquiry and those called as witnesses, had nothing to gain, and perhaps a lot to lose, by exposing faulty work. After all, the NBR had declared its intention to rebuild, or replace, the Tay Bridge, as well as build an even greater one across the Forth. Engineers who alienated the hierarchy of the NBR might eliminate themselves from those lucrative future contracts.

Only the chairman, Rothery, seems to have been in an impartial position, but he appears to have been so determined to prove bad workmanship that he neglected all the evidence of a derailment.

Why pier 28 (the last one on the low girders out from Wormit) survived with all its cross bracing loose is rather a mystery, but the damage to pier 33 must have been sufficient to cause the next four girders to collapse and they in turn caused the next four to collapse. Again, why pier 41 (the northern end one of the low approach girders) survived is not clear.

I have always considered that the forces required to burst four rails, even at their fishplates, far exceeded the wind force on any one girder during the gale. In my opinion, the real mystery is why any of the bridge survived.

Today I believe we can be sure that some of the workmanship was not as bad as was at times made out at the Inquiry. The rivets used in all the girders were much criticised (by a clerk) for quality, but when the Inquiry closed and the lawyers went home, the surviving girders, still riveted with these very rivets, were transferred lock, stock and barrel to the new bridge. There they still have years of useful life ahead of them carrying trains far heavier than Bouch could have imagined and surviving gales far worse than on the night of the disaster. They provide a fascinating link with the world's most infamous railway accident.

The first Tay Bridge as built was going to fall down sooner or later thanks to the alteration in the plans, the inferior construction, and the inadequate maintenance. Was its demise hastened by a derailment caused primarily by a rogue girder? We shall probably never know for certain, but there is a fascination in attempting to find a scenario which fits all the known details which the Inquiry Reports so blatantly neglected. This is what I have attempted to do.

BUILDING A DISASTER!

To accompany this article, and to explain the construction of the first Tay Bridge in greater detail *The Scots Magazine* has arranged an illustrated talk by Bill Dow on the anniversary of the night of the Disaster, Thursday 28th December. It will be held in the Steps Theatre, Victoria Road, Dundee and starts at 7.30 p.m. Tickets, £1.50, can be purchased from the Sales Counter, Bank Street, Dundee, or by post by sending a cheque or postal order made out to D. C. Thomson & Co. Ltd. to *The Scots Magazine* Lecture, 9 Bank Street, Dundee DD1 9HU (please remember to enclose a stamped, addressed envelope).