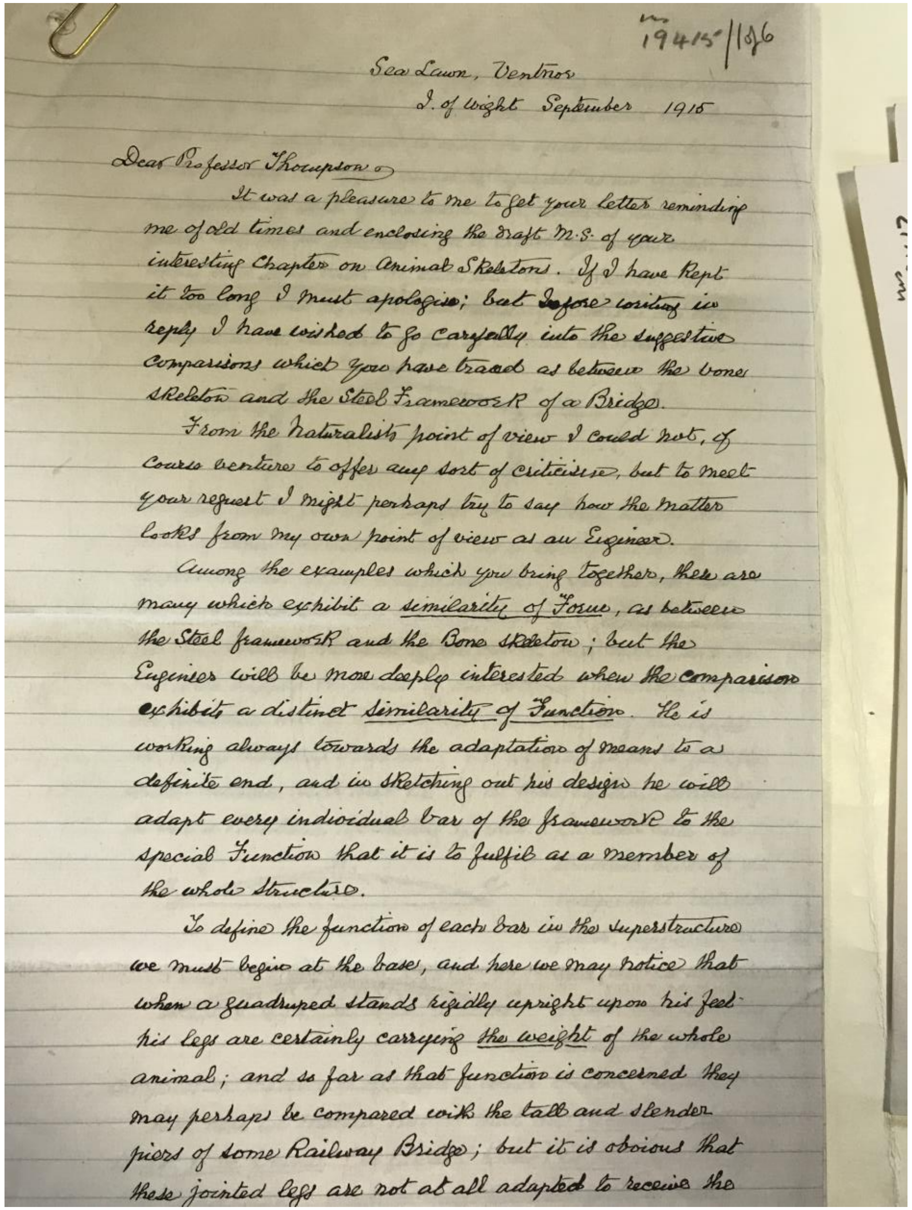


Sea Lawn, Ventnor
I. of Wight September 1915

Dear Professor Thompson,

It was a pleasure to me to get your letter reminding me of old times and enclosing the draft M.S. of your interesting Chapter on Animal Skeletons. If I have kept it too long I must apologise; but before writing in reply I have wished to go carefully into the suggestive comparisons which you have traced as between the bone skeleton and the Steel Framework of a Bridge.

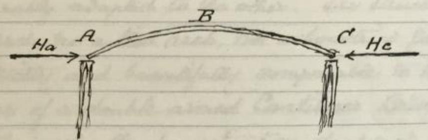
From the Naturalists point of view I could not, of course venture to offer any sort of criticism, but to meet your request I might perhaps try to say how the matter looks from my own point of view as an Engineer.

Among the examples which you bring together, there are many which exhibit a similarity of Form, as between the Steel framework and the Bone skeleton; but the Engineer will be more deeply interested when the comparison exhibits a distinct similarity of Function. He is working always towards the adaptation of means to a definite end, and in sketching out his design he will adapt every individual bar of the framework to the special Function that it is to fulfil as a member of the whole Structure.

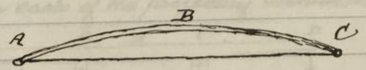
To define the function of each bar in the superstructure we must begin at the base, and here we may notice that when a quadruped stands rigidly upright upon his feet his legs are certainly carrying the weight of the whole animal; and so far as that function is concerned they may perhaps be compared with the tall and slender piers of some Railway Bridge; but it is obvious that these jointed legs are not at all adapted to receive the

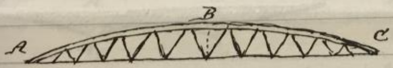
- Many examples exhibit a similarity of **form** (steel framework and bone skeleton) but better to look at similarity of **function**.
- Function of each part:
  - Base: When a quadruped stands upright on its feet, the legs are carrying the weight of the whole animal. Compared to the tall and slender piers[?} of a railway bridge.

the horizontal thrust of any arch that may be placed upon the top of them. Hence it follows that the curved back-bone of the horse, which appears to cross the span between his shoulders and his hips, cannot be regarded as an Arch – in the engineering sense of the word. It resembles an arch in form but not in function, for it cannot act as an arch unless it is held back at each end by the horizontal reactions H_a and H_c, and those necessary reactions are not present in the structure so far as we have considered it.



But your paper goes on to suggest that we can supply the place of these external reactions by a modification of the superstructure in one way or another – and so we can. Thus for example we may begin by inserting a straight steel tie AC, uniting the ends of the curved Rib ABC, and the tie will supply the place of the external reactions, converting the structure into a "Tied Arch" (as in the roof-principals at many Railway Stations. Or we may go on to fill the space between arch and tie by a web-system, converting it into a Parabolic Bowstring Girder. In either case the structure becomes an independent, "detached girder", supported at each end but not otherwise fixed, and consisting essentially of an upper compression member ABC and a lower tension member AC.





But here we should notice that the necessary tie AC is not to be found (so far as I know) in the skeleton of the quadruped: ~~[illegible]~~

- Jointed legs not adapted to receive the horizontal thrust of any arch placed on the top of them. (curved back bone of horse cannot be regarded as an arch - not held back at each end by horizontal reactions)
- Can supply the place of these external reactions by a modification. i.e. insert a straight steel tie to unite the ends and supply the external reactions. (tied-arch). Can fill in gap by a web-system (parabolic bowstring girder)
- Now consists of an upper compression member and lower tension member.
- Necessary tie in bridges not found in skeleton of the quadruped.

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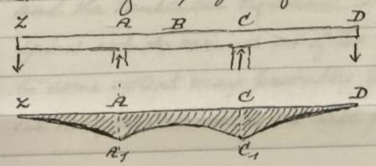
It seems to me therefore that there is little to be gained by referring to these ~~curved~~ bow-string ~~structures~~, for they do not in themselves represent the framework that we actually find in the animal skeleton, nor do they represent any framework that would be suitably adapted to the actual distribution of loads and supporting forces.

But if we look at the actual distribution of loads and the actual design of the animal skeleton, we find (as you have so forcibly pointed out) that the one is most admirably adapted to the other. The structure is not an arch, nor a tied arch, nor a bowstring girder, but is strictly and beautifully comparable to the Main Girder of a double armed Cantilever Bridge.

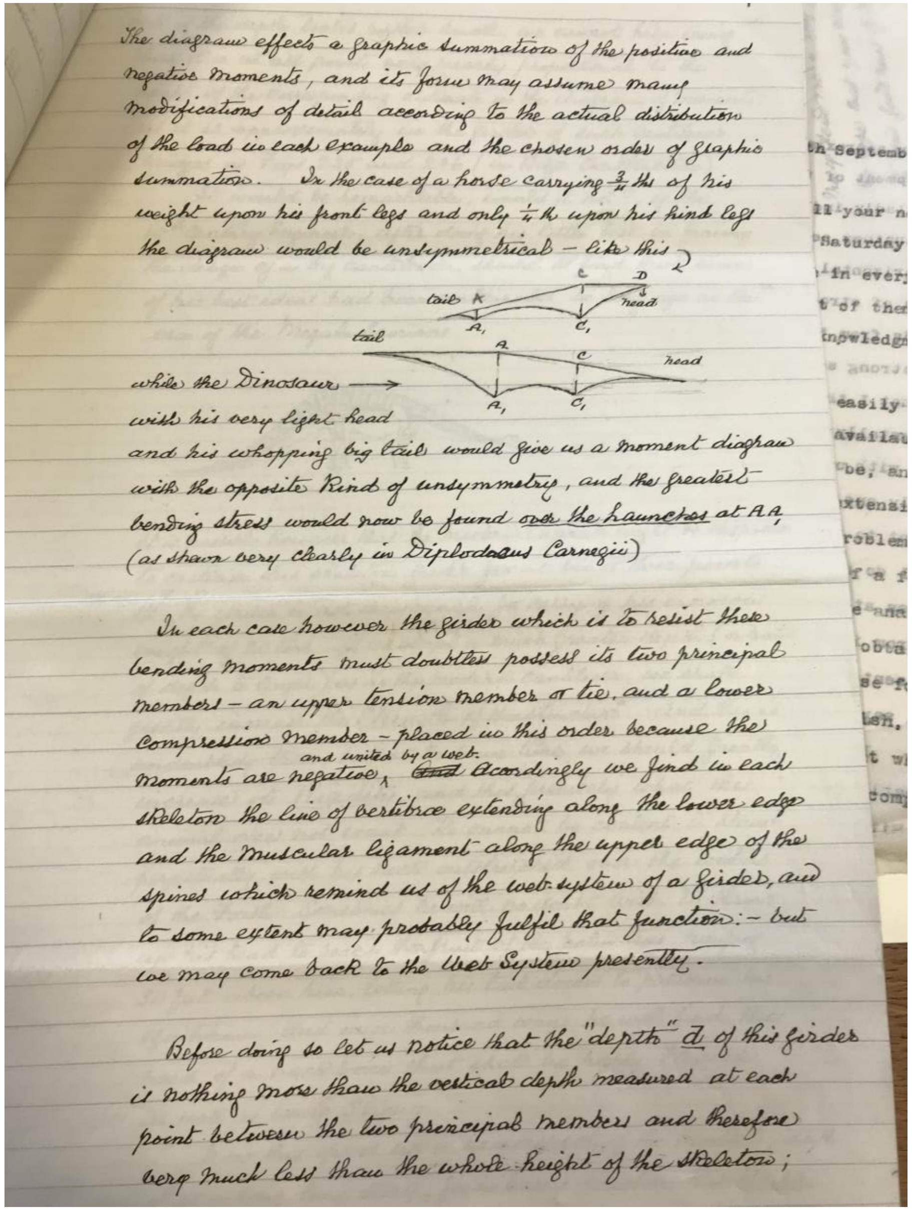
Obviously the superstructure does not terminate at the two points of Support A and C, but extends beyond them at each end, carrying the head at one end and the tail at the other ~~end~~ upon a pair of projecting arms or Cantilevers AZ and CD.

This girder is, of course not "continuous" over two or more spans for there is only one, but it is effectively continuous from the head to the tip of the tail; and at each point of support (A and C) it is subjected to the Negative Bending Moment due to the overhanging load on each of the projecting cantilevers AZ and CD.



The Diagram of Bending Moments will lie below the base line ZD (because the moments are negative), and must take some such form as the shaded area in this figure: so that the girder will suffer its greatest bending stress – not at the centre but at the two points of support A and C where the moments are measured by the ordinates AA_1 and CC_1.

- Structure of animal skeleton most comparable to the main girder of a double-armed Cantilever Bridge.
- Does not terminate at two end points but extends beyond them, carrying head at one end and tail at other.
- At each point of support, it is subjected to negative bending moment due to the overhanging load.



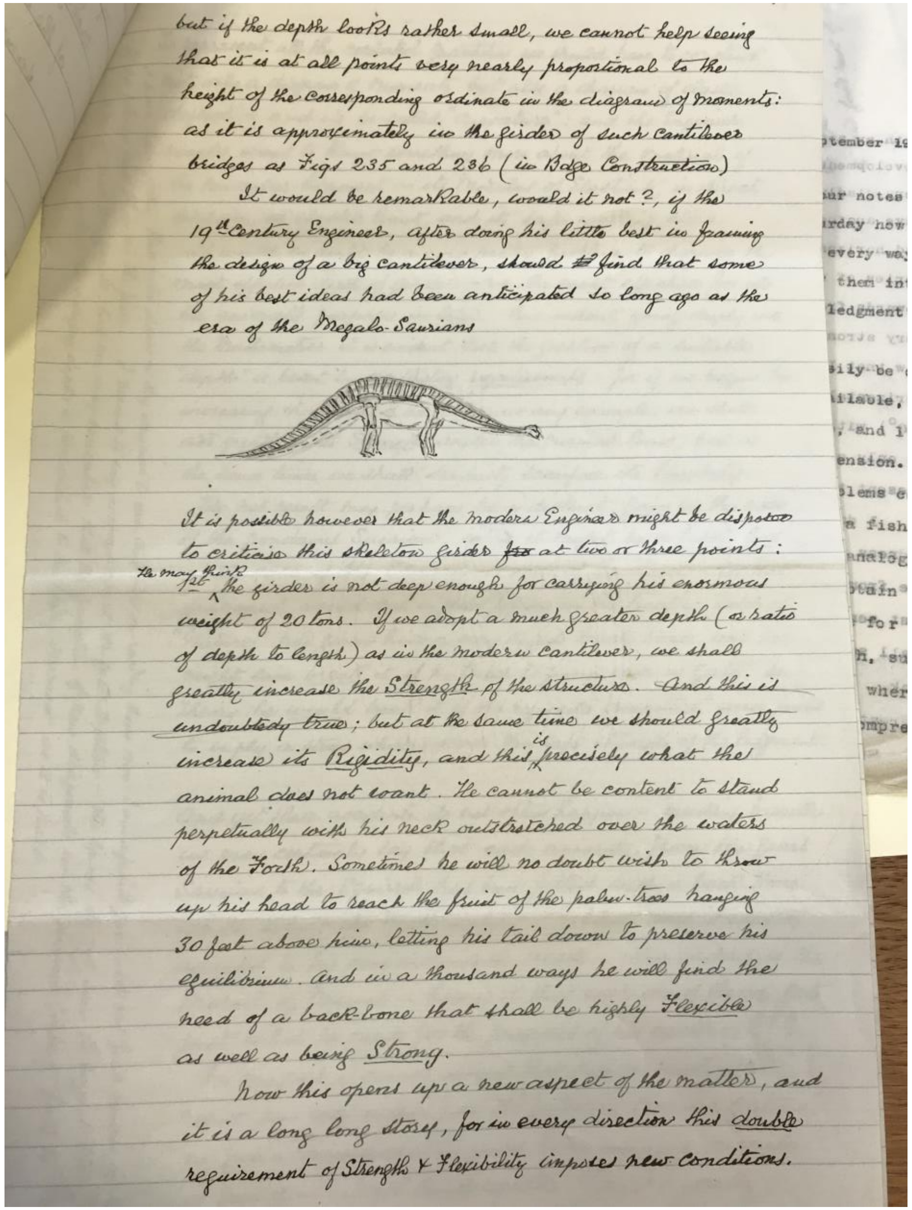
The diagram effects a graphic summation of the positive and negative moments, and its form may assume many modifications of detail according to the actual distribution of the load in each example and the chosen order of graphic summation. In the case of a horse carrying $\frac{3}{4}$ ths of his weight upon his front legs and only $\frac{1}{4}$ th upon his hind legs the diagram would be unsymmetrical – like this

while the Dinosaur →
with his very light head
and his whopping big tail would give us a moment diagram with the opposite kind of unsymmetry, and the greatest bending stress would now be found over the haunches at A A, (as shown very clearly in Diplodocus Carnegii)

In each case however the girder which is to resist these bending moments must doubtless possess its two principal members – an upper tension member or tie, and a lower compression member – placed in this order because the moments are negative, and united by a web. Accordingly we find in each skeleton the line of vertebrae extending along the lower edge and the muscular ligament along the upper edge of the spines which remind us of the web-system of a girder, and to some extent may probably fulfil that function:– but we may come back to the Web System presently.

Before doing so let us notice that the "depth" d of this girder is nothing more than the vertical depth measured at each point between the two principal members and therefore very much less than the whole height of the skeleton;

- Many modifications due to actual distribution of the load. For example, the horse carries more weight on front legs than hind legs so unsymmetrical as in diagram and opposite for dinosaur due to light head and heavy tail. (greatest bending stress found over the haunches)
- The girders which resist these bending movements must possess an upper tension member (tie) and lower compression member)
- In skeleton, we find the line of vertebrae extending along the lower edge and the muscular ligament along the upper edge of the spines. (similar to web-system)
- Depth of this girder = vertical depth at each point between the upper and lower member. Much less than height of skeleton.



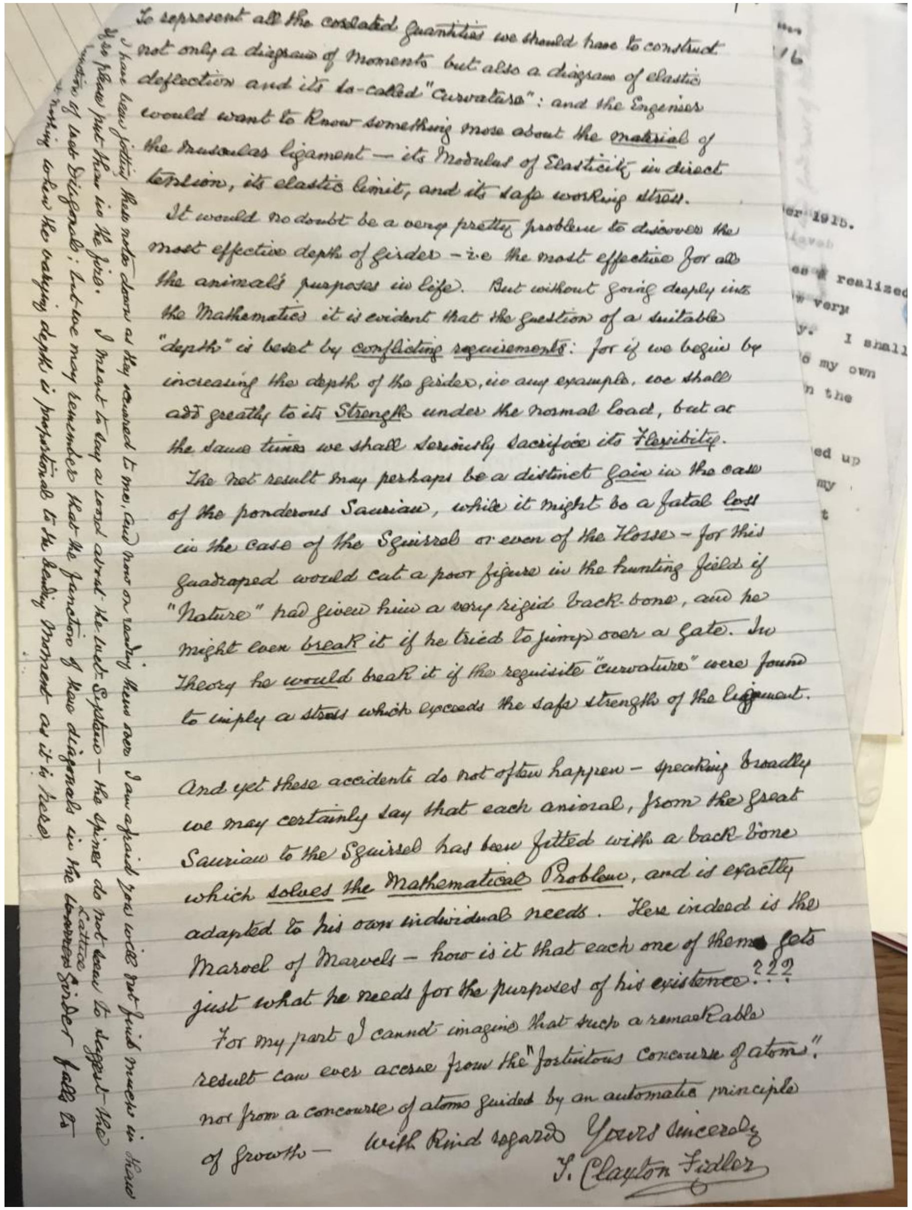
but if the depth looks rather small, we cannot help seeing that it is at all points very nearly proportional to the height of the corresponding ordinate in the diagram of moments: as it is approximately in the girder of such Cantilever bridges as Figs 235 and 236 (in Bridge Construction)

It would be remarkable, would it not?, if the 19th Century Engineer, after doing his little best in framing the design of a big cantilever, should ~~#~~ find that some of his best ideas had been anticipated so long ago as the era of the Megalo-Saurians

It is possible however that the modern Engineer might be disposed to criticise this skeleton girder ~~for~~ at two or three points: 1st He may think the girder is not deep enough for carrying his enormous weight of 20 tons. If we adopt a much greater depth (or ratio of depth to length) as in the modern cantilever, we shall greatly increase the <u>Strength</u> of the structure. And this is undoubtedly true; but at the same time we should greatly increase its <u>Rigidity</u>, and this is precisely what the animal does not want. He cannot be content to stand perpetually with his neck outstretched over the waters of the Forth. Sometimes he will no doubt wish to throw up his head to reach the fruit of the palm-tree hanging 30 feet above him, letting his tail down to preserve his equilibrium. And in a thousand ways he will find the need of a back-bone that shall be highly <u>Flexible</u> as well as being <u>Strong</u>.

Now this opens up a new aspect of the matter, and it is a long long story, for in every direction this <u>double</u> requirement of Strength & Flexibility impose new conditions.

- Engineers of today may criticise the skeleton structure of the dinosaur:
    - Girder not deep enough for carrying enormous weight. By adopting a greater depth would increase the strength of the structure. However would also increase rigidity.



To represent all the correlated quantities we should have to construct not only a diagram of Moments but also a diagram of elastic deflection and its so-called "Curvature": and the Engineer would want to know something more about the _material_ of the muscular ligament — its Modulus of Elasticity in direct tension, its elastic limit, and its safe working stress.

It would no doubt be a very pretty problem to discover the most effective depth of girder — i.e the most effective for all the animal's purposes in life. But without going deeply into the Mathematics it is evident that the question of a suitable "depth" is beset by _conflicting requirements_: for if we begin by increasing the depth of the girder, in any example, we shall add greatly to its _Strength_ under the normal load, but at the same time we shall seriously sacrifice its _Flexibility_.

The net result may perhaps be a distinct _gain_ in the case of the ponderous Saurian, while it might be a fatal _loss_ in the case of the Squirrel or even of the Horse — for this quadruped would cut a poor figure in the hunting field if "Nature" had given him a very rigid back-bone, and he might even _break_ it if he tried to jump over a gate. In Theory he _would_ break it if the requisite "curvature" were found to imply a stress which exceeds the safe strength of the ligament.

And yet these accidents do not often happen — speaking broadly we may certainly say that each animal, from the great Saurian to the Squirrel has been fitted with a back-bone which _solves the Mathematical Problem_, and is exactly adapted to his own individual needs. Here indeed is the Marvel of Marvels — how is it that each one of them gets just what he needs for the purposes of his existence???

For my part I cannot imagine that such a remarkable result can ever accrue from the "fortuitous concourse of atoms", nor from a concourse of atoms guided by an automatic principle of growth —

With kind regards Yours sincerely
T. Claxton Fidler

I have been jotting these notes down as they occurred to me, and now on reading them over I am afraid you will not find much in them so please put them in the fire. I meant to say a word about the Web [?] System — the Spines do not seem to suggest the function of web [?] Diagonals; but we may remember that the function of these diagonals in the ~~braced~~ [?] Lattice Girder falls to nothing when the varying depth is proportional to the bending Moment as it is here.

- Double requirement of strength and flexibility.
- Elastic deflection, curvature and material of the muscular ligament needs to be considered.
- Suitable depth of girder beset by conflicting requirements: e.g. increasing depth increases strength but reduces flexibility.
- Each animal has been fitted with a backbone which solves the mathematical problem and fits its individual needs.