Flexure Analogy to Crane Runway Girders, Is It Blessing or Curse?

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"Be practical" whether we spoke of the term as fad or proclaimed to have acted out in practice seemed not much harm or no harms in general. But depending on what makes good/better/best sense and what is more important, to pin down what in realism does **practicality** stand for in association with Common Structural Engineering Design Principles is rather difficult if not clear of what timing we are on and what motivation was behind.

"Practicality" could be as straightforward as a stance taken from the mix bag of those elements deemed conservative, simple, prudent, realistic, pseudo-realistic or trouble-free, etc., or from combining whatever that fits the inspiration, yours or mine.

Whether if more or less often than our normal acceptance of being conservative or not, but the fact is, not every popular engineering approaches, assumptions, conjectures or design schemes, etc. once considered **practical**, **flawless or ideal** could stay being practical or ideal forever.

> The irony:
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> Come what may whichever strategy was chosen for a given task, there could have been "positive effects" favoring a certain optimistic consequence at one point, but then there could be "negative impacts" reeling in thereafter whether on account of direct or indirect design *oversights* or plain *wrongdoings*. Thus what deemed practical or impractical would highly depend on what, where and when the adopted strategy makes the best sense aptly for what application and for what occasion that were prescribed

The appraisal of any specific engineering strategy as being practical or not could be quite subjective, which is more so applicable with respect to **Crane Runway Girder** (**CRG**) related matters, for instance:

> To simplify the treatment to *open symmetrical-sectioned **CRG** under torsion*, the applied torque moment pivoting about the global **Z**-axis through **shear center** – let **X**, **Y** and **Z** to be parallel with flange, web and longitudinal axis, respectively – was often resolved into a *flange-force coupling* per classic **Flexural Analogy**

Assuming the **shear center** had been *properly located* for the subsequent discussion:

Flexural Analogy is a typical example of engineering approximation (idealization) of a rather complex **3D** structural incidence, which is coerced into a somewhat shortchanged structural behavior mimicking how an applied torque would limit itself to behave − as if of no faults or harms done on **CRG's** behalf − within a *local* **2D** cross section based on *local* static equilibrium maintained in the *local* **XY** plane.

> Imagine a clockwise torque is applied to an ***I****-shaped two-flanged* beam, when looking into the "warped" profile, we see the top flange deflects to the right while bottom flange repels to the left. Ostensibly so when viewing the deformed shape in **2D**, it seemed merely by the look as if the external torque can be broken down into a pair of (linear) flange forces counterbalancing each other along the one-dimensional **X**-axis maintained in the **XY** plane. By mocking the effect with such analogy, logically there would be +**Fx** pushes top flange to the right and –**Fx** pushes bottom flange to the left
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> Accordingly, it simulates the "**3D** torsional response" into a "**2D** confine" *as if the structural behavior is entirely independent* of certain higher-ordered torsional effects subsisted in the **X/Y** dimensions − supposedly it works out only up to a point – seemed no one talks much about what's missing there.
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> *Nevertheless, it is not entirely* <u>*illogical*</u> *if* ***Flexural Analogy*** *were commended by the not-so-totally-untrue physics fortified within the* ***XY*** *plane, but by which the rendered torque value, to match it numerically, would only make* <u>*numerical sense*</u> *if it were compelled into a "product" taken from multiplying a linear force of a certain quantity by a moment arm of a certain length*

What happens is; the ***true torsion-based*** *warping normal stresses in the flanges are* <u>*substituted*</u> *with* ***flexure analogy-based*** *lateral bending stresses.*

Albeit both bending stress and warping stress are acting along local ***z****-axis but with a big difference. The deformed profile under bending remains plane while that under warping is distorted.*

Remember flexure analogy does not engage the girder web into the action at all while torsion does, which contributed to the so-called restraining effect that flexure analogy lacks. That might not cause much of a problem when applying flexure analogy to **non-CRGs**. But, as far as *unsymmetrical sectioned crane runway girders* are concerned – as we are focusing exclusively on **CRGs** − is it still **OK** to exchange warping normal stress with lateral bending stress? More specifically, how could **Flexural Analogy** take hold as if there isn't any hidden blind spot?

> *Again, the* <u>*flexure analogy-based web*</u> *(1) was not engaged to have any influence to what was going on and (2) had not contributed any restraining effect to what the flanges are doing.* All seemed fit for "**regular** symmetrical sectioned **I**-shaped two-flanged members" per static equilibrium based on these (unsustainable) expediencies for that:

- The two flanges are parallel to each other − *think about, <u>what if</u> the flanges were not drawn parallel to each other due to geometric imperfection from wear and tear, how could the force vectors be maintained in equilibrium and what does the free-body force diagram look like?*

- The cross section must have only two flanges only, and no more – *then think about:*

  (a) *<u>What if</u> from end to end there exists a longitudinal stiffener (bar, plate, angle or channel, etc.) protruding continuously from one side or both sides of the web?*

  (b) *<u>What if</u> attached directly under the bottom flange there is provision of a third flange/web as reinforcement being an integral part of an inverted tee?*

  (c) *<u>What if</u> through connection with a thrust plate, a third-forth flange supplemented from afar that was brought in line/parallel with the main girder top flange?*

  Glossing over by the “simplified **2D** approach” per **Flexural Analogy**, if only that was adopted for design of regular symmetrical sectioned **I**-shaped **non-CRG** members (or the ones with cap-channel) then, such an oversimplification would and could have turned away some if not the bulk of dreary efforts from having to deal with the less (or more) convoluted effects versus what it takes to do the “real thing” the proper way

  However, it could be disadvantageous if not all that risky in certain applications involving some of those aforementioned “*<u>what ifs</u>*” when the objectives were misused into a somewhat bogus engineering solution, in particular for unsymmetrical-sectioned members outfitted with multiple webs and flanges

On the surface, there seemed nothing (or not much) to lose by means of simplification by reason since no one has questions. But, once going into the detail on the defense of using that sort of *simplification* across the board, whether taking those very realistic “*what ifs*” into consideration or not, have we not thought about what could be really missing if we were technically serious or curious on what truly happens?

Just think about a few important specifics, even for **I**-shaped **CRG** members, from mocking the torsional effect through **Flexural Analogy**:

- The seesawing "*enhancing-restraining* **effect** may come close in terms of effect along the longitudinal **z**-fibers but the effect due to rotation about **XY** plane from warping torsion" would have been *wrong if not by choice*

  Wrong? To certain extent that is, with no consideration that warping effect can cause (1) higher-ordered *torsion-related* shearing behavior in the **XY** plane and can change (2) some of the fiber lengths along **Z**-dimension, which induces distortion (non-uniform deformation) of **XY** plane in the cross section (with fiber stress subsisting everywhere including the web, not just confined in the girder flanges only)

- Knowing that the exact level of control as to limiting the rotation about global **Z**–axis is critical to the *wellbeing of the crane rail* situated over the girder flange, but as opposed to formalizing the true structural behavior of "open-sectioned members under torsion" with structural responses that supposedly takes place in a **3D** space, this faux **2D** simulation messes up the numerical accuracy in computation of **global angular rotation θ** about **Z**-axis – truly hidden in sight a garbage-in-garbage-out situation that a lot of engineers ignored – so then *serviceability evaluation is flawed*

- In addition to taking into account the effect from flexural shear, something equally important is missing, too. The girder web would be discounted or shortchanged in providing resistance to a certain brand of shearing effect innate in torsion that must be evaluated from **θ' and θ'''** – *especially for built-up girders at the interface among many bolted/welded components*

Whereas if not critiquing too harshly in a too old-schooled manner, but be fair only to arbitrate strictly on the matter of "simplification" out of taking it technically easy into sacrificing accuracy in calculation of specific class of structural response to loads, is that **OK**?

> Some of us could still make a case so as if justified for being conservative in terms of longitudinal bending stress evaluated at the extreme fibers of flanges, by which if applying **Flexure Analogy** in that aspect can be proven conservative but we must ask, what is the big problem for being conservative?
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> To certain structural configuration mixed in with design conditions associated with most **non-CRG** applications, the end results minus any unfavorable byproduct from using **Flexure Analogy** could give out an impression of no big deal or totally harmless, what's-wrong that is
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> And for **CRGs**, beyond taking the said approach voluntarily, some might have overlooked the practical notion buried in such a sketchy idea that it works out harmlessly only if by luck sometimes by ignoring effects from **θ' and θ'''**, and most of all, provided that we have absolutely no worry about how the ultimate performance of the structure could have been compromised by ignoring some

of the less obvious shortcomings; of significance, say, shall we not be anxious to know:

- How about the <u>serviceability provision</u> of overestimated or underestimated (lateral and vertical) deflection at the crane rail elevation by discarding the warping restraining and/or relaxing effect? In a way without an accurate value of **θ** then how to qualify deflection limit to, say, **L**/600 or **L**/1000 or whichever/whatever that specified in the design criteria?

- How about the <u>legitimacy</u> in establishing a rational shear-flow pattern: *Pitting web-connected shear-flow against web-disconnected flexural shear-flow, would they complementing or enhancing each other's threat to structure?* Think hard on this one as we are dealing with unsymmetrical sectioned **CRGs**

- Regarding the <u>engineering concern</u> of whether if at certain **X/Y/Z**-coordinate(s) the cross section with critical connection detail feature(s), how could that not be vulnerable to shear failure, particularly from shear fatigue – not shear buckling – in long/thin elements by totally ignoring effects from **θ' and θ'''?**

  Consequently, the calculation of shear reversal becomes impossible and the evaluation against shear fatigue is impossible. As a result, every engineering calculation related to "shear" is bogus.

As always, it pays to think twice and don't follow some of the so-called custom(s) so blindly

The choice of whether (1) to ignore the important issue completely with no regret or (2) to cover up the bared shortcoming with "whoops" or "don't worry" should only be "approved" by a responsible party who should identify all the valid reasons as to why it is **OK** to "take **Flexure Analogy** for granted" as so, for whom (Clients,) for what type of structure (of what configuration) and for which application, etc.

To **unsymmetrical-sectioned CRG members**, applying simplification or not is a limited "conditional" choice, not entirely up to a willful personal choice. When taking that route, certain structural qualification issues must be addressed prior to imposing a somewhat technically questionable shear-flow scheme based on **Flexure Analogy**:

Be cautious whenever making a personal choice of ways and means:

The **shear stress reversal** calculation as part of the fatigue assessment using **Flexural Analogy** has not been established as truly conservative or trouble-free at all − in particular for *girders with web stiffeners* − not to mention as prerequisite that external torques and internal torsion(s) must be correctly and accurately balanced and quantified to begin with, which in turn from doing so as chosen, one has to make sure that all the backup engineering intelligence must be traceable starting from a correctly and accurately located **shear center** (see the looming issue?)

With all due respect to its **non-CRG** usages, applying **Flexure Analogy** pointlessly may further the misunderstanding of many key issues on hand for **CRG's** sake. In addition, it is more than likely that in some cases **Flexure Analogy** may turn out unrealistic or provide unfavorable results – becoming a *design loose end* – as opposed to taking on torsion exceedingly serious at close range.