Open Sectioned Crane Runway Girders with Arbitrary Profile Geometry

Chapter 4 – Ready, Set, Prepare To Go Yet?

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If someone decided that **Open Sectioned Crane Runway Girders** (**CRGs**) should be given a special rank of their own then those having **unsymmetrical sectioned profile** should deserve much more, because they stood out for plenty of good reasons, in particular by traits of:

- The applied load resultant is consistently at *offset* from the **Shear Center**
- The applied load resultant is at *skew* from the **Elastic Principal Axes** on regular basis
- And above all, the location of **Elastic Centroid** *never concur* with the **Shear Center**

Those listed are not complete by all means, but we see the issues and can readily decode much of the complexity embroiled in the handling of structures of this caliber − having **unsymmetrical sectioned profiles** − was embedded deeply in the atypical relationship between the **applied loads** and the **profile geometric features**.

4.1 Who Is To Blame?

No one is to be blamed yet,

> Despite our obligatory acceptance of (1) the non-modifiable way of how *crane loads were applied* and (2) the innate *irregularity* in the *profile geometry*, even though rationally we might be readied to take on the unavoidable challenge and to endure through the burdensome workout, but situation could change once we started "playing" with those issues; because various **technical** adversities *concealed* behind the planning and execution of **Engineering Qualification Process** could break loose in multiple passes, one after another

On the whole, each **CRG** project is unique in its own way. Albeit one project could be *different* from another in certain aspects, but it is quite common when running *typical* **CRG Engineering Errands** during the structural analysis and design qualification sessions, we might encounter *numerical-data-nurtured* inconvenience, surprise or disarray that could drop in on us following several paths:

- As in (1) making sense of the **never-again-simple-bending- privileged** structural behaviors attributed to loads off **shear center** and in (2) allocating, extracting and backtracking of extreme effects duly enveloped from all probable moving load scenarios

- And to great extent in establishing an effective strategy tending to the massive amount of information cropped up throughout the process

While meeting design qualification mandates and getting by with less frustration – as to minimizing the run-in with numerical disarray − as design process progresses, quite noticeably rather trendy these days that many **CRGs** were configured with **symmetrical sectioned profile** appeasing both practical and sensible causes. That is by choice a much wiser preference and resolve contrasting those with no better options yet caught up with much less privileged configuration involving unsymmetrical sectioned members – an inevitable *must-be-dealt-with* condition inbuilt in many *forensic* and *upgrading* projects.

In retrospect, quite plausibly that – when opined at *sophistication level* from a *Fabrication Detailers' perspective* rather than *Engineering-Mechanics' standpoint* − unsymmetrical-sectioned girders were widely accepted once upon a thought that they were much more **practical** in their own right.

> Thereby so many not-so-regularly-shaped members were so *intuitively* configured, so *inadequately* qualified yet so *consciously* implemented all along in so many facilities in the Industry worldwide
>
> The catch:
>
> What was popular back in those days now bequeaths an everlasting speculation becoming rather unfavorable to so many Facility Owners' Maintenance/Operation teams of late for the least; the come-to-be compensations they've gotten or have troubled to put up with, if at all, could be flip-flopping from (1) what *at best* a seemingly no-fault sense of security, yet still toiling behind an insecure sensation wondering whether if all girders on hand could survive till the end to (2) what *at worst* a high and dry certainty, yet still battling with an ambiguous outlook whether some of the girders could ever live up to their useful life

Quite visibly from here on out, we can't let the ongoing downhearted issue quietly slip through right behind (or right in front of) us as if nothing had happened:

> From a subjective viewpoint not so much of conceptual measures but by looking closely at those gloomy track records gathered from (latest or historical) field monitoring and inspection proceedings, as the range of these *not-so-optimistic findings* became more and more widespread, and the count of unfavorable rulings kept mounting at each pass, so, wouldn't it be more pressing now than ever (1) to reconnect our general awareness toward such concern and (2) to contrive from our ingenuity into truly **practical** means aiming to *prolong, salvage and revitalize* those **CRGs** in need?

The scapegoats, if at all not too many to place blame on but then:

- Was it the fault of loads being applied *too unconventionally*?
- Or was it the fault of cross sectional geometry being *too unsymmetrical*?
- Or were there any *loose ends* in how these structures were qualified and detailed, after all?

What is to blame based solely on the above is not important for the moment but we shall see. Granted we all knew the fault is not the loads, neither is the section geometry. Yet most of all, one must agree with one thing, these *not-so-optimistic field findings* revealed in the (latest or historical) inspection reports do not become an eyesore or pocketbook-sore in one day, and that's for sure. Then at whichever level of soreness that may cause to whomever is another matter but, harshly speaking, we − the engineers − could have committed our share of *wrongdoings* in some way:

- If we insisted on applying **LRFD** (*read on*) for everything or
- If we relied on using **finite element method** for everything (*see upcoming chapter*) or
- If we failed to fully qualify the structure against all probable failure modes, and
- Most of all, it's a no-no if ever we miss-located the correct location of **Shear Center**, etc.

4.2 Design Loose Ends, Are There or Were There?

"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:
>
> 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, all 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
>
> 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
>
> Nevertheless, it is not entirely illogical 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 numerical sense 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 substituted with **flexure analogy-based** lateral bending stresses.

Albeit both bending stress and warping normal stress are acting along local **z**-axis but with a big difference, notice that 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 flexure analogy-based web (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, what if 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) *What if 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) *What if 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) *What if 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 "*what ifs*" 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 as stated 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 **Flexural Analogy** is, for it omits the detail 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 the fact that:

  (1) Controlling the rotation **θ** about global **Z**–axis is critical to the *wellbeing of the crane rail*, (2) the genuine behavior of open-sectioned **CRGs** under torsion must measure up in **3D**, (3) the faux **2D** simulation would blur up the numerical accuracy in the computation of **global angular rotation θ** about **Z**-axis

  What truly hidden out of sight, with respect to deflection at rail top, is a *garbage-in-garbage-out* situation that a lot of engineers had ignored; in consequence, the *serviceability evaluation is flawed*

- In addition to taking into account the effect from flexural shear, something equally important is also missing; 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*

By taking **Flexural Analogy**, it does bring out greater amount of longitudinal stress than the warping normal stress in the flanges, but it ignored the shear in the web entirely. If we (1) try not to critique too harshly in a too old-schooled manner and (2) to be fair to arbitrate strictly on the missing web shear then, is that **OK**?

Again, by sticking with **Flexure Analogy**, some could make a case and be content with greater amount of longitudinal bending stress in the flanges; so what is wrong in this picture?

> That works in most **non**-**CRG** applications involving **non**-**CRG** design conditions qualified with **non**-**CRG** design mandates, the end results minus any unfavorable byproduct from using **Flexure Analogy** could give out an impression of no big deal or totally harmless, and that is what's-wrong

To simplify the design of **CRGs**, many engineers opt for **Flexure Analogy** voluntarily and ignore the effects attributed to **θ**, **θ' and θ'''**, and some would overplay that their structures analyzed-designed by virtue of **Flexure Analogy** are functioning "flawlessly" yet with no knowledge that such scheme works out merely by luck. Sure it thrives, but they have no idea of the ultimate performance of the structure could have been compromised by ignoring some of the less (or more) obvious shortcomings such as:

- How about the serviceability provision 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 can anyone qualify deflection limit to, say, **L**/600 or **L**/1000 or whichever/whatever that specified in the design criteria?

- How about the legitimacy 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 engineering concern 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 seriously and don't follow some of the so-called tradition(s) so blindly

Exclusively on the design of **CRGs**, the choice of ignoring the important issues cited earlier with no regret – in a way to cover up the obvious shortcomings that may come with − should only be "approved" by a responsible party who should elucidate the reasons as to why it is **OK** to "take **Flexure Analogy** for granted" otherwise think twice

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, which is the major motivation behind our yet to be committed "**CRG Engineering Strategy by some Other Means.**"

4.3 Engineering Oversight?

On a negative note to start:

Looking back at the *engineering process* for conventional structures with respect to provision of a lasting in-service functional competence from a durability standpoint – as far as **CRGs** are concerned − in the good old days, what lacking then is a **practical** course/procedure that could be universally followed so **collectively** to produce commendable results in terms of upholding in-service structural performance for the long haul; although a lot of us might not "see" it that way right away.

On negative note once more:

It is all with reference to the timing of "when" it happens − *although providentially not happening at this very moment yet − but in due course, a lot of* ***CRGs*** *would fail (or experience catastrophic failures) if we don't start making a change.*

Normally, for a trivial defect(s) obscured in certain local component − *in case of base metal with hairline crack, for instance* − to develop into a perceptible status and flourish into a major event affecting production or even jeopardizing structural support function, it might take a very lengthy while to play out that course and make real to be exposed. That is why a lot of us might not "see" it that way right away

That said was not a postulation or else things might not happen exactly that way; but when it does take place then there has to be a justified (justifiable) explanation to that effect. While we were not digging into the bottom reason "why" it happens just yet, but we could at least picture the probable "how so" in slow motion of a vastly realistic situation out of many *not-so-fortunate* **CRGs** that are (already) in need of dire attentions at present time if not exaggerating.

Herein as follow is the typical account:

> Supposedly from the outset as the girders were designed duly by the original specifications, all were expected to endure whatever the intended loads as applied and to last through the anticipated number of live load on/off application cycles as so projected – *as we would think so*
>
> Somewhere there is a big puzzle:
>
> Should our structure (1) as configured with its interfacing connections as detailed (fabricated) and (2) our design approach as adopted (executed) for the Structural Engineering Process were **flawless** then, why prior to the coming of age that some of these girders would suffer telltale aggressions from metal **fatigue** if from nothing else more explicit?
>
> Leaving our unsolicited Structural Engineering Opinions aside for now but seeing through our wary eyes at close-up inspection into those flawed or distressed girders, to which for sure "sensible" questions could be raised by many Seasoned Structure Inspectors, and by some of the Laymen Observers as well, more specifically:
>
> > *Why does it crack here, and not there, or why (not) anywhere (else) at all*?
>
> Realizing the seriousness of matter to ask questions upfront is a good sign, but with so much uncertainty and so many probable/improbable reasons known and unknown … one may wonder:
>
> > *Was there any inexcusable **engineering oversight**?*

It shouldn't be much dispute on a fact that any eventual plight out of metal fatigue on conditions predestined to happen will eventually happen no matter if that comes from:

- **Inadvertent Oversights** in the initial **engineering conception** or
- **Inherent Flaws** in the initial **engineering process**
- **Lapses** in qualifying the initial **design-detailing of critical connections**

> Seriously, that should cast a shadowy spell to any brand of structures including **CRG** and **non-CRG** configured with any geometric features regardless if they were long, short, slim, symmetrical or unsymmetrical sectioned, etc.

Metal fatigue is an ultimate exhibition of progressive propagation of flaws rooted from the **engineering-detailing review and design qualification procedure**, which could ensue from overlooking a number of design-detailing issues involving section properties, load responses and/or stress analysis, etc. that should have been taken care of in a proper **technically-correct** manner. To name a few design loose ends:

- Underestimated the implication from excessive on-off/advance-reverse live load application cycles and the eccentric load application natures

- Miscalculated the **shear center** coordinate, **Py-δx** and/or **Px-δy** effects induced by imperfections (intrinsic or acquired)

- Overrated the structural strength against yielding and/or metal fatigue due to tensile stress fluctuation and especially the shear stress reversal effect

- Misjudged the combined causes through using inadequate or unqualified engineering ways and means, etc.

Despite the inadequacy as subtle as sampled above, shouldn't all the design loose ends be taken into account under the original design agenda and be avoided in the first place?

> *Or if not mistaken, were there uncharted Hits or Misses in the **traditional** approach with respect to how these girders were **idealized**, **modeled**, **analyzed**, **qualified, detailed** and **fabricated**?*
>
> To get a hint − not an answer − one needs to look no further than the latest inspection reports on some of these older girders (some newer ones, too) to agree that there is no shortage of evidence supporting the fact that design loose ends do exist

The not-so-favorable reality for **CRG**:

> Once structural distress was ruled in existence, the fate cannot be changed and the distress cannot be reversed unless properly fixed *in time*; or else it sure would secure a lasting association with unkindness from being forever **fatigue-challenged**
>
> Then in any event, why wait for the ultimate plight to emerge near the end of (or beyond) the structure's service life and then to make costly amend? In order to prevent any of our **already or not yet fatigue-challenged CRGs** from being **sitting targets**, wouldn't it be more amiable to ask our own selves:
>
> *Aren't we able to foresee and put a stop to those unwanted (eventual) failures from metal fatigue at the initial design stage?*

More to our high hopes:

> If the **traditional means** failed largely in turning out **fatigue-proof CRGs** meeting our and Facility Owners' expectation of structural durability goal then, wouldn't now be the perfect moment to revamp the outdated − to some extent flawed − process into some "**other means**" that works, at least hopefully?
>
> On the other hand, unless there existed from other sources a much better fail-safe way out of the ongoing **CRG** design doldrums already, anyone of us who is in for similar longings may find it more interesting (or if not more boring) after giving the so-called "**other means**" a chance and see if it could help tightening up those design loose ends

It follows that, while on track of investigating the formerly troubled unsymmetrical sectioned **CRGs** − in particular those with long-standing repair history − no matter if they were inadequately designed or poorly fabricated with **fatigue-challenged** connection details or not, but one of the right things to do is that, only after achieving a thorough **understanding** of how the structure **as designed and as detailed** truly performs in actual Service/Operation through (1) correlating data accumulated from field monitoring programs and (2) timely scheduled inspections, etc., otherwise it would never be so blatant for us to grasp what could make up those design loose ends, let alone tighten them up whether by the same old means as usual or by whatever the "**other means**" if there is one.

4.4 Before The Other Means, What Does It Really Mean?

Supposing all design loose ends were cast in past tense, once they were clearly identified and rationalized in present tense, then the questions:

> Could those loose ends be tightened up and fixed up by some **re-engineered** (other) means? And is it really not a fancy hope but a goal readily feasible?

The answer depends, and we won't get there any time soon. But at the least, we need to (1) recognize there has been a problem, (2) understand why a girder fails and (3) find out how our "same-old ways and means" had brought to the current **CRG** muddles, etc.

Under contemporary design <u>obligation</u> catering to all ranks of structure on equal footing, it won't be a big issue normally as long as we follow the Code-intended directive properly. But for the **Engineering of Unsymmetrical Sectioned CRG's** <u>interest</u> as of this writing, there isn't any head-to-toe type of Design Guide(s) or Code directive to follow.

So whether the structures were doomed or yet to be, unless we admit to the fact that there is "some" bygone **CRG** engineering inadequacy or else there won't be much success in getting out of the same-old.

First of all with no further disdain we should hold off efforts to continue drawing on those ineffective or bad old structural qualification schemes, ways and fixes, etc.

Secondly, instead of falling back on to the comfortable "same old same-olds" in defense of the past, we should put in more vigor into the re-engineering measures drawn from catching up on how everything works based on analyzing the structure's <u>in-service performance time history</u> accumulated through stages − both before and after the structures were put in service − or else we won't be able to fully appreciate what effort it would take to implement such re-engineered engineering fixes, *not only re-engineering the structure but also the vital engineering process*

If we were serious in a full-course pressing with "technical appreciation" of how structures truly behave under loads being applied in such an eccentric manner as those **CRGs** were subjected to then it would only be wasting our time <u>unless</u> we resolved to "spy on and drill deeply into" every little detail from square one.

So then from square one − whether attempting the feat manually on pieces of scratch paper or through serious automation − it may well worth the wisdom or the foolishness cultivated from investigating the analytical results based on not just one single trial but on several separate sessions involving radically different tactics. In Authors' opinion it could take a lot out of one's staying power, and the mission may go as so:

- Starting from one extreme − the easy way − involving the use of simplest scheme, which could be launched right along the friendliest course of our chosen by applying all *validated* assumptions and simplifications so long as they were (proven?) technically reasonable

- Then continuing on into the furthest extreme – the hard way − finishing the assignment off using the most meticulous approach (if there is one) by nurturing all the cruel physics and mathematics, more importantly, without missing any technical requisites in due course provided that we have the *patience, the know-how and the proper tools*, etc.

- After it's done, do a comparison of the results summarized from each scheme. Only after then could the rightful pros and cons be settled over the issues on whether it is better using or not at all employing any (*unreasonable or questionable*) assumptions or simplifications

All that as outlined would sound too far fetching or too abstract at the moment. But for **CRG** longevity's sake, we shouldn't cease to learn the rights from wrongs or ignore any key element of cognitive defeat from our (bygone) misjudgment, which would only be more appreciative perhaps from hard-learned experiences, especially those of the <u>legal kind</u>:

The fact is: What we do could (and would) bring about undue troubles to **CRG** structure should we misinterpret or act carelessly about the interaction and influence from a <u>variety of crafty structural implications</u> from those **poorly analyzed, poorly designed and/or poorly detailed** components that were meant to last through "structural eternity;" and that is no escape **even for members of doubly symmetrical profile**. Sounded more abstract, or just a tall tale?

Finally the main question:

> *What is the so-called "**other means**?"*
>
> To begin with what is not, this method employs neither "**Flexural Analogy**" nor solution by way of "**Finite Element Method**." And despite all as if not going along with the (wrong) flow or standing by the (questionable) norm, this "***other means***" remains being a "**full-fledged**" structural engineering process, **and may be much more** once we get into the deep

The analytical approach being encouraged and so dubbed herein being the "***other means***" is an all-inclusive engineering process as we shall see along the way. It pleads no excuses or any other reasons but to take on the connotation from several **hot topics** that often were "ill-treated" or "overlooked" in practices.

And ostensibly although none of the **hot topics** seemed as much welcoming to embark on for those Practitioners not fully geared up for; but fortunately all that had been very well preached from Classic Engineering-Mechanics Coursework. Anyhow, a brief overview of these topics may be essential:

(a) By and large "**Torsion**" would grab the most attention among all forms of load application (load response) on open sectioned members; it is known to wreak havoc big time if mishandled or ignored

To avoid messing with it the hard way if nothing else is more serious then, anyone could still insist on the good old **Flexural Analogy** as surrogate out of one's own free will, just be careful it appeared palpable only (on the conservative side in certain aspects but not all) for symmetrical **I**-sections or get by with some of the **non**-**CRG** applications. *What that means is don't try it on **CRG** especially those having unsymmetrical section*

(b) Then not as pesky as torsion, but "**Unsymmetrical Bending**" would always creep in from behind loads applied at skew with the **principal elastic axes**, which were sometimes confused or misaligned to correlate with geometric axes of other significance. If not thoroughly understood, this subject could cause further confusion when mixed up by the common adjective "unsymmetrical" with the generalized flexural behavior of unsymmetrical sections

(c) Lastly but not the least, the worst adversary that could bestow onto **CRG** and probably the most boring subject of all, but found time and again overlooked, misunderstood or mistreated when coming down to the blessing of engineering design towards structural longevity: **Fatigue**

Many Designers may (or may not) be quite familiar with **S-N** curve in this regard yet perhaps not very well versed with how to harness it effectively in actual practice. Those eager to become expedient at tackling the **practical** issues in "qualifying **CRG** against metal fatigue" would probably face the same old dilemma with same old feeling that there isn't a great deal of guidance to go easy with

It is rather appalling that the design requirement for metal fatigue has been well outlined and well organized for quite a while in the traditional **AISC** intent and yet still hardly any **truly practical** design examples were given in the public domain with much needed details tailored on **CRG's** behalf from classic Textbooks or Design Guides (as of this writing)

4.5 Facing the Challenges

Already, Structural Engineers needn't be jack of all trades, but would certainly be better off being conversant with a wealth of buzz terms in **CRG** interest, those should at least include *"Moving Loads," "Unsymmetrical Sections," "Shear Center," "Lifted Capacity," "Warping Constant," "Trolley Weight," "Torsion" and "Metal Fatigue" besides "Yielding" and "Local Buckling,"* etc.

With each as listed being *<u>independent subject</u>* of interest, there were plenty of theoretical materials for academic and **R&D** reasons as to gaining *readily-available knowledge* into any one of those buzz terms. And yet ironically one might be curious that:

> To gear up for benefiting **CRG Engineering-design Intent** and even for **Regular Structural Engineering Design Consumption**, how often or how seldom have we seen these *readily-available knowledge* <u>collaborated</u> together all in one place into a comprehensive package aiming for Engineers' more organized <u>surviving and problem-solving purpose</u> and not just for Scholars' piecemeal <u>learning and grade-passing purpose</u>?

Although "*Engineering Learning*" in the classrooms − or in front of screens − and "*Engineering Living*" in one's career were driven and commanded by completely different states of mind, but that difference would grow even furtherly spaced out whenever humbled by unexpected discordance, more specifically in making such distinction:

> If only for "learning purpose" while the Textbook theory on certain subjects was established too challenging to comprehend then,
>
> > One or anyone being a student could always exercise options of either (1) drilling it in much more diligently to the bottom or (2) dropping off learning initiative entirely, or (3) hanging on barely, or (4) resorting to taking shortcuts, and so on
>
> On the other hand, there is not much of choice when facing serious challenge in real life engineering career:
>
> > If for subsisting by the specified project mandate (making a living we meant) whereby being challenged then, one can only let that be and deal with it **ASAP** be better or worse, and that's the way of real life in the real world, not just engineering life
> >
> > But in any case, one could still have choices of taking shortcuts (not knowing if it's right or wrong) or else toughening it through (not knowing how difficult that is,) but either way only if it works out for the final reward (not knowing if still getting paid fully or being shortchanged) despite inference of any other kind

Yet no matter what drives and what not, in the thick of a professional-graded **CRG** setback, how fortunate would it be if our wishful thinking of a "Genuine Design Guide" would come true and hit upon us in time?

> Just be clear for the moment, <u>what in need</u> is not the recurring ineffectuality but the real deal; from which there better be collection of instructions or guidance giving details with focus (1) into how does unsymmetrical sectioned **CRGs** truly behave *under intended loads*, and (2) into tips as to understanding why some of their components would fail prematurely *under intended loads*, etc. so that everyone could (1) carry on with undertaking of **CRG** engineering or re-engineering for the Industry at large and (2) with that turning out better functioning structures that actually *perform well and be long lasting*

If, and only if ever so aspirant to surviving the **CRG** design challenges in a **complete** and **clear-cut** manner without corner-cutting, and with a similar attentiveness like that being taken in by enough number of enthusiasts like us then, as result hopefully, someway somehow those aforementioned buzz-worded topics could be re-sampled, re-purposed , re-organized and re-inferred beyond Textbook Theories into overt and useful inferences – i.e. defying however scary, unexciting, uninteresting, confusing or boring the *combination of these subjects* might seem.

But a long time passing, leading *from* truthful understanding of those buzzing topics and attending to their full implications *into* truly useful Guidance towards common **CRG** objective (ours and our Clients' as well,) there appeared very little surefire direction on what must be done and what not, especially not much on "practical" warnings on when or where to take "**justified shortcuts**" or "**zero shortcuts at all**."

One can safely deduce as far as **CRGs** are concerned, without a full-blown consolidation of all buzzing engineering topics forming a tactically superimposed process or application on their behalf, all these piecemeal topics in their existence are nothing but many broken links or pieces. In a way, the process of engineering problem solution if failed to engage all necessary technical components in one integral session then it is equivalent to solving it by taking unjustified shortcut.

> On the whole, any engineering schemes fueled on shortcuts and so commissioned as to simplifying a complex process should always be authenticated by already-challenged technical workouts. Whereas with so little conclusive modern-day **R&D** inferences as backup on unsymmetrical sections' behalf, the attempt of articulating design shortcuts for structures with unusual attributes such as those **CRGs** with inborn irregularities in both the *section geometry* and *loading nature* would be rather risky
>
> But unfortunately so as it has been so far, the bulk of itty-bitty guidance there is, be that contemporary or classic especially for unsymmetrical sectioned **CRGs**, seemed rather elusive, piecemeal, much too simplified or for the worse misguided into the "same old treatments" appeared suiting only symmetrical sections befitting simple-bending behavior and/or other non-**CRG** structures mandated with non-fatigue relevance, *and that's the most dangerous part*

Anyhow, the solution workout tactic being advanced as part of this "***other means***" should at least take in several familiar steps as summarized as follows:

- Compiling structural geometric modeling information and loading criteria
- Performing analysis and enveloping structural responses
- Calculating stress, deformation and tie-back forces, and
- Post-processing for structural assessment and reporting, etc.

By this surprisingly brief listing as itemized, it really doesn't amount to anything out of the ordinary from such a simplified workout "plot." It appeared far from being anything groundbreaking; except for **as committed** the few characteristic attempts that may be worth pointed out as follow:

- The leading **Structural Engineering Plot** revealed under this **other means:** Meeting head on with the combined consequence from (1) torsion, (2) unsymmetrical bending and (3) fatigue among other technical side effects deemed relevant

- It maintains taking "no shortcuts" during the process to matters whether of technical- or non-technical related, otherwise it would defeat the purpose of the whole idea of "being complete"

Understandably, the solution strategy framed up behind such "plan" or "plot" could be challenging (if not enough said) and tricky to **implement** even though the processing flow appeared quite straightforward in essence. It may seem too ambitious as to carrying out the "plan" the hard way as insinuated, but it is not impossible to craft a feasible approach and follow through with all associated details (yet to be revealed in the upcoming **Chapters**)

Exercising the committed process meticulously through each and every step "as required and as planned" is much more difficult than by taking conditional shortcuts – such as **flexure analogy** − on established procedures. But regardless, one should sort out the pre-analysis mindset on many key issues prior to the coming of any achievement in this undertaking.

> Forewarning:
>
> *There is a fair chance of getting nothing much out of such endeavor but a total failure, and likely that all efforts in "meeting the challenge" could be proven wasting time in the end*

Nevertheless from the grandest perspective per Authors' past experiences and ongoing efforts, what could hamper our task the most may not be all that from making the calculations − however complex that may be − but more so from how to ***effectively*** *maintain the numerical accuracy, manage the data depository and make senses from the enormous amount of data*, etc.

4.6 New and Used, Experienced and Inexperienced

Whether we "see" it or not:

> Speaking of our general perception taken to the **Engineering** of **Crane Runway Girders**, there might be false impression ingrained in our intellect affecting an individual's baseline approach to **CRG** matters emanated between (1) <u>creating</u> brand new girders and (2) <u>mending, modifying, upgrading and renewing (re-engineering)</u> the structures that fall under the scope of **Rehab or Replacement and/or Upgrading Projects.**

Looking from the most fundamental level, even though the analytical-design procedure for both **CRG** and **non-CRG** structures is on the "same engineering principle" but it is never that straightforward to forestall what it takes to claim a total victory over <u>re-engineering mission</u> – to either type of structure – owing to one small (or big) detail:

> What comes with **Rehab or Replacement and/or Upgrading Projects** (**RUP)** is the demand in our extra watchfulness on structural members/components that were not brand new but in distress – especially those vividly deformed out of shape or in severely worn and torn conditions – while meeting many field-driven challenges and resolving constructability-related issues, etc.
>
> The handling of **RUPs** often beckons efforts far beyond applying basic engineering principles. Naturally it commands more than "regular" desktop engineering skills whereas furthest respects ought to be spared to a lot of deceivingly simple, trivial, unkind realities and situations innate in almost "all" **RUPs**

<u>On cutting to the chase when hitting upon those well-worn **CRGs** in **RUP**</u>:

> When showing our face on a scouting trip, it pays to keep all "technical" <u>eyes</u> and <u>minds</u> widely opened at all times. In other words it is much better to "anticipate" surprises at all levels of all depths; so be prepared to take in what comes our way and those sneaking behind our back as well
>
> Site-unique surprises usually take their own pace to expose themselves; that is why some of which still need to be "hunted for" if not being "seen" yet. As to hyping up those out-of-sight incidents – not evident to our prying eyes or not yet materially present on the as-planned **RUP** timetables – with due respect, all were recognized as "Surprises" for good reason
>
> The best situation is "seeing" (1) the "surprises" being exposed just in time or (2) those already caught up with as-needed attentions. No matter what were out there already, be local episodes or already prevalent system-wide, which is in a better situation for there is not much (or nothing) can be done to those concealed unseen ones that stayed dormant until their dawning or that brewing in progression pending some ill-timed eventual revelation befitting a much bigger surprise
>
> Depending on the seriousness of matter on hand, certain "Surprises" could put on the look of petty small nags to the untrained many as if innocuous to their eyes or ears. Yet cluster of unattended surprises could cause major inconvenience to Mill Production, or even those on the milder side, they still require routine monitoring or some remedial actions to ride it out until fatefully the day to call for serious repair or some re-engineering action, etc.

With luck or no luck it all depends; the state of many **RUP** affairs may start out as if "not so doomed" yet but could be "destined" to end with a surprising outcomes; on the down side sometimes it was so ill-fated so big time barely from titbits of our (bygone?) **engineering negligence** and/or **detailing sloppiness**:

> Whether the **RUP**'s fixing result ended up being *truly beneficial* or *more harmful* to the structure highly depends on how the already confirmed **surprises** together with the **non-surprising issues** were administered – only if not mistreated or overlooked

At face value as limited by however long/short the outage was to last, execution of **RUP** seemed a hurry-up time-crunching business as always; that said, but expecting a final score to be registered of any just-completed **RUP** is nothing but a slow-going time-grinding game.

In almost all cases what that means is, even though the **RUP** desktop engineering and field contract activities for the project had come to a close but no one can claim the prize yet – except maybe a temporary victory for meeting the *must-get-it-done* deadline – and so it implies what accomplished then was only the groundwork, whatever the spawning follwing that time frame hinges upon lots of unknown yet to come about over a long haul. In a way it could take years or decades before one can appraise or condemn whether the **RUP** was properly engineered or poorly engineered.

> Depending on the experience level in handling **RUPs** and the varieties of **surprises** that came with, some of the (key) issues could:
>
> - Have not been "seen" in full detail or have been "missed" entirely by the <u>inspection branch</u>,
> - Or be acknowledged only for record logging purpose yet not (properly) dealt with at all by the supposedly entrusted <u>technical branch</u>,
> - Or on principle the state of affairs was diagnosed and treated but on balance the "recommended fix" was not fully financed or supported by the <u>fiscal branch</u> for proper just-in-time action and so forth

What may develop when **undesirable situations** prevail? Once again, depending on the Project Team's handling experience, the net outcome may end up:

> - As if not fixing anything at all – typical from superficial copy-paste projects,
> - Much effort spent but far from what expected for lack of a cure-all recipe, or
> - Reaching somewhere in between yet still nothing substantial accomplished, etc.
>
> Not uncommon even if the subject/object issue in focus does get fixed (*symbolically?*) but barely up to an inconsequential extent because the technical dosages were too weak to heal the wounds, or for worse, the *prescribed* fixes were *outright ineffective or incorrect*
>
> Speaking of *ineffective or incorrect* repairs, so often a seemingly well-intended engineering achievement would instead turn into an unintended punishment to the structure; all that was advanced by no one else but by some or all of us involved – including the Engineers and/or Detailers or Fabricators of common trait – such a despicable finale so bestowed is not surprising from among those inexperienced "Low Bidders" if only they so admit; there it goes the *buy-it-cheap ended up buying it twice or more;* what an **irony to realize cheap equals expensive**

More specifically, here's a case in point that the responsible Engineers should be aware of:

> It may work out under certain **non**-**CRG** project setting via normal **A/E-inclusive** contract – on division of work related to connection detailing assignment – to fudge a familiar engineering initiative with a halfhearted finishing touch by means of etching the famous "By Others" phrase stamped onto the official engineering documents as <u>cover up</u> could be a very bad move – bad in

terms of fulfilment of time-critical **CRG**-related contract, because for **RUPs** *there is no sense to hinder the project progress having it done by others but ourselves*. That is like pushing *feigned engineering-detailing solution* without actually taking the full responsibility

One of the worst of all should be the misdiagnosis of structural-life-threatening symptoms collectively into normal wear and tear thus leaving the conditions virtually as is or turning it into a cut-rated replace-in-kind project without digging deep enough to "see" whether if the issues were consequential from bygone "bad detailing," "bad engineering approach," "bad fabrication QC" or "bad management" besides not knowing bad anything or bad everything else

And yet in the end just ask our own selves, how often have these misdiagnosed or mistreated conditions were doomed further beyond much worsened conditions, not once, but over and over?

Consider a situation just as not-that-good, but with a different twist that the Facility Owner should avoid:

There could be numerous interpretations from seeing through various traits of "**RUP Surprises**," even though serious headaches had turned up to whom it may have concerns or were felt by the experienced-inexperienced Facility Engineering/Maintenance/Operation team, but how many times have these symptoms been tended to *professionally*, or put off *willfully* or *forcefully*, if not by "innocent engineering ignorance" but by political-driven thrifty savings through "low budget" or "no budget" kind of **Band-Aids**/**Aspirins** fixes, wrong fixes, zero or negative fix is the question

More than likely so, those Aspirins/Band-Aided fixes were "cosmetic repairs" often applied in emergency situation in a crunch when short of no better choice. But if such practices were so wildly endorsed lacking solid engineering backup, then at best it would only help clearing the dreadful symptoms in the short run, which rarely can catch/match up with the genuine fixes that aimed at ridding the root causes. *Trouble is, a lot of Facility Owners fall for the Aspirin/Band Aided fixes*

Again, so often while getting on with metal-fatigue-prevention movements, the majority of Structural Engineers seemed to favor more with exclusive interest on issues with respect to "tension" only; and hardly ever touch on "shear" at all.

One thing that gets most engineers confused is not aware of the fact a zone stressed with mild tension can experience very serious shear stress reversal that led to metal fatigue from the interaction between flexure and torsion. To equalize the train of thought for example, we should have said:

One of the worst and yet most common Band-Aided actions taken against "cover-plated girders" should be the case of applying "***weld across any element experiencing tensile fluctuation***" but scarcely mentioning the same no-no is equally applicable to "***weld along or across any element experiencing shear reversal***"

Notice that the so noted ***element*** of interest hereinbefore could be referring to both flange-like and web-like elements in terms of stress pattern. Just remember out of flexure importance alone, not only stress can come from **Mc / I** but can also come from **VQ / Ib**

To **non-CRG** structures, if there is advantage of patching a cover plate to thicken an ***element*** then it might at best be an effective supplement to much needed **non-fatigue strength** at relatively low cost, meanwhile to **CRGs**, the matching fix could be much more harmful or detrimental in the long run if the **strength** against **fatigue** of that ***element*** plus the connection were not duly qualified *by the Book, we meant the real Book*

Nevertheless some of the layover problems though well masked behind Band-Aids, if not truly superficial in nature, could only be worth in values up to its relative "low cost" or reaping results as "low quality or effectiveness" as bought, and sooner or later the same problems would likely recur and deteriorate thus furthering the structure into bigger troubles; experience tells that none of the problems would ever go away without a properly engineered fix as blessing. Haven't heard or seen that before is quite normal to us, the Engineers, but not so to many facility owners though

On saving, spending or wasting wisely:

Certainly a comprehensive re-engineering/re-construction project costs way more than makeshift Band-Aided fix in terms of time and money, but don't go too cheap too tempted too soon; if the condition warrants the provision of generous and rigorous repair mission then it is not wise to be penny-pinching or profit/production-pushing any longer; or else there'll come a day through which the situations could end up being so serious that the inevitable repair work could lead to a lengthy shutdown on top of carrying a hefty price tag rung up to seven or eight digits in dollars equivalent to a major surgical event, and that is not unheard of. *In that case, it is worth to learn a lesson but not so much even if the responsible personnel gets fired because the damage was already done*

Therefore when facing **RUP**-related issues, no matter the persistent kind or the fleeting kind, we should weight in on with our technical eyes widely opened and prudently evaluate the situation:

- What are the advantage and benefit from using our (not someone else's) solution scheme?
- Was the chosen scheme effective, technically justified and validated?
- What if the scheme failed to offer better (or no) solution to the problem at all?
- Finally, could we skirt around some of the *inconvenient issues* already identified?

Not thinking in those terms yet? It might be just fine lest we have much better plans. But, certain actions if taken too frankly or turned the as-planned pages too soon too rapidly might be harmful as a whole. The bottom line is, not seeing or not solving it does not mean the problem is going away, <u>for instances</u>:

(a) To plead for endorsement of unjustifiable self-appropriated technical excuses − by over-simplifying the design qualification procedure supposedly fully attributable to unsymmetrical section geometry or any unusual girder profile geometry, or

(b) To do not enough or nothing about the unsightly permanent deformation − warps, twists, bows of structure or the excessive rail snaking/misalignment, or

(c) To ignore chronic distress in structures or worn rails as already documented – that kept recurring themselves in series of inspection reports, or

(d) To end the **RUP** short of delivering a fix-it-once-and-good-for-all repair – ended up repeating same old repairs after same old repairs over those same wounds never were healed, etc.

All in all, no two Engineers are exactly alike in the depth of sense or wisdom over an identical structural issue. Speaking of differences in their "feeling" towards pure Structural Engineering matters:

Some of the genuine **CRG** headaches or outcries for help in **RUP** were quite audible to those been-there-done-that or well-in-the-loop ones yet the same could seem muffled from many inexperienced or naive others

There's another misconception that stems from a rather novice thought out of those not so novice but novice-skilled Structural Engineers who would persist that all structures under the same class must be all equal under the sun, hence designing new girders is same as fixing the old ones, thereby in their mind there shouldn't be worry of those as-said realities or surprises known exclusively to **RUP** thinking the problems, if any, were on the other side of the court, not theirs

Then again, no two Engineers are exactly alike in their dealing with "issues and demands" combining both engineering and non-engineering concerns, in terms of which:

With respect to ostensible differences in the outlook on **RUP**,

> Plant Engineers (Operations, Maintenance and/or Management) in the Mills representing the Client side, usually, were much more **turnkey-project oriented** beyond "pure" engineering services whereas in contrast, Consulting Engineers and/or Practitioners mostly familiar (exclusively) with non-field oriented **A/E** Design Services might be much more wrapped up in **single track minded** rationale bounded by very strict or limited work scope in terms of field-driven issues

What exemplified thus far seemed to strong-arm a rather atypical **RUP** impression into the deep-rooted regular **A/E** norm, which is unquestionably "traditional" by tradition

It would be much easier to reorient ourselves into **RUP** state of mind by taking in a genuine wisdom on how to deal with instantaneous (yet unexpected) surprises rather than static routine **A/E** matters; meanwhile be prepared that the Mills, in general, might have more dynamic "ideas" in the project agenda and work scope definitions than those ordinary Engineers or ordinary **A/E** Firms could ever appreciate unless they had "felt" through **RUPs** many times over from beginning to the end and experienced what it's like having from head to toes the tickly-painful-turnkey-project moods

After all, the planning for **RUP** and execution of which should be founded on a high-caliber turnkey frame of mind as just pointed out so that the <u>ultimate project success</u> would turn up more naturally from more seamless collaboration of efforts out of all disciplines through <u>successful on-site project management</u> − undeniably true, definitely not from playing selfish ego games

Besides working up a nominal budget commitment to the project and because each Facility's issue is exceptional in its own way, accordingly, the art is in how to predict the proper amount for hidden proceeds in terms of spontaneous extras to be shelled out throughout **RUP** process.

To master the ins and outs of **RUP** budgeting it sure went way beyond pure engineering matters out of single track minded perspective, which some of the "low-bidders" or inexperienced dare devils can never fully identify with. And thus no wonder there were drastic differences − some so out of proportion − in the bids not only in dollar figure but also in the quantity and quality of the deliverables.

All that might well explain the reason why some of the **CRG** dare devils-in-disguise could offer emergency Band-Aids fix at such (unethically) low or high Engineering Cost and got away with it, in due process punishing unfairly price- and quality-wise those much experienced others − who with all good intent to probe meticulously into the **root causes** of the problems and provide value-added solution applicable system-wide most amiable to the overall structural integrity – unfortunately someone somewhere sometimes gave in to those "unqualified" low/high bidders that happened again and again.

In spite of having an **RUP**-trained structural treatment mindset, and since:

(a) Being confident that there are radical difference in the demand of "project engineering sophistication" into the aged old **CRG** and that into the brand new unborn **CRG** and

(b) Being proficient in identifying how a structural component has suffered from *cosmetic* or *skin-deep* illness at local "component" level

Then having such experiences after dealing with diverse issues through many **RUPs**, why not and how can't we not be <u>more successful</u> the next time around (1) in curing the sick ones being repaired and (2) in better crafting those "future" unborn **CRGs**?

What had been advertised in the interim is (1) to be taught from the oldies in the "wrong" and (2) do the new ones with more "right" and keep them in the "right" for good. It makes better sense to tender a more proactive thinking while framing the foremost engineering approach or design hypothesis:

> Unless some of these unkind but probable "out of the norm" **RUP surprises** or **effects** were incorporated as part of the "no more surprise" initial project design criteria when designing these **new CRGs**, otherwise whatever the destined distresses or upset symptoms innate in any structures owing to careless design, if not imminent, would eventually come through in the open for sure, only in matter of years later if not any sooner

One thing for sure and it's good to know in many **RUPs**:

Any persistent distress if found common in structures of like feature time after time then definitely there is an unresolved tight spot hidden somewhere. Sometimes taking care of all that could be easier than it sounds in principle, but as already said it is well worth the effort in "tending to all the cruel physics" first and much of that would be deliberated further – just read on.

4.7 Scope of Coverage

If not noted otherwise, all references made to **CRG** appearing in this Series from here and on would imply the worst combination setting of:

- ***Open Sectioned Crane Runway Girders with Arbitrary Profile Geometry*** *and*
- ***Girders inherited from Rehab or Replacement and/or Upgrading Projects (RUP)***

Nevertheless, herein the term **Unsymmetrical Section** applies to irregularity only in the profile geometric configuration − unlike the dealing specifically with material properties of hybrid girders, for instance, of different yield strength or Young's modulus as typified in many classic articles documented elsewhere

Notice that many numerical expressions or formulations may carry a generic "±" sign preceding certain terms signaling that the entity of interest could bear either a positive "+" or a minus "–" sign as result of:

- *Reversal in vector senses of the applied load*
- *The applicable floating **X**-offset dimension as measured (1) between the true crane wheel load point and the installed **rail** centerline, (2) between the load point and girder's **elastic centroid** or (3) between the load and girder's **shear center**, etc.*
- *Fluctuation or reversal in the resulting global structural responses to applied load or sign change in internal stresses*

Prior to utilizing any specifics from herein to **CRG Engineering Application**, Readers should always turn to other controlling resources on **CRG** design essentials and guidelines mandated in project relevant Codes, established Industrial Standards and/or plant-specific criteria as applicable. Materials already introduced in **Chapters 1 through 3** would likely not be repeated from here and on unless worth being reemphasized to make a lasting impression.

Tackling **CRG-related Problems** takes much more than the endeavors in pursuing personal hobbies; and it all starts from those commonsense subjects already covered. Herein some of the information might seem as if not quite linked up with the main theme but are very important to be on familiar terms with before doing anything else.

As we could see so far:

There is no palpable logic in reasons why certain topics precede others. While making the best attempt to have everything organized short and sweet, but because the relevance among many subjects may be intertwined in very intricate ways, thus there may be duplicated opinions − those reappearing as required on the same subject beyond the respective paragraphs where they all started or ended − given that they may be expressed with different technical *twists and turns* here and there, or be left off intentionally wherever as convenient as being resolved or unresolved to invite further study or confirmation.

4.8 LRFD and ASD

At this early stage whether to follow **LRFD** or **ASD** into executing a particular plan is not the point of debate here since each standard had its respective status in normal practices.

> But at the project level, picking out a proper method as basis to qualify the design of a specific class of structure should be the most important commitment any responsible project personnel has to make before going about engineering business as usual
>
> In the meantime one shouldn't gloss over the fact that a great number of Structural Engineers designing **CRG** and a variety of many other structural objects had elected **ASD** for various reasons even though **LRFD** was endorsed officially for quite a while

Since **AISC** (since the Black Book edition as of this writing) is so well articulated in integrating the strategy of treating **LRFD** and **ASD** in parallel, apart from the loading combination details, it makes little difference going either way once the "Nominal Design Strength" is obtained through common sets of Code Equations that are equally applicable to **LRFD** and **ASD**. Among others, some of the familiar distinctions between the two paradigms were:

(a) Respective load combination definition:

LRFD deals with load combination factors specific to strength limit states while **ASD** deals with a separate set of combination load factors applicable to design based on allowable strength

(b) Application rule in defining relevant "Required Strength":

Applying a resistance factor (Phi **Φ**) for **LRFD** and safety factor (Omega **Ω**) for **ASD** (see **AISC Chapter B**)

Like in everything else we do, judgment applies:

> As of this writing per Commentary of **AISC** Section **B3.4**, **the typical relationship between Φ and Ω is mostly based on a live load-to-dead load ratio of 3 for "*braced compact beams in flexure and tension members at yield …*"**
>
> On stopping by the phrase "**mostly based on a live load-to-dead load ratio of 3**," it makes one wonder does that mean there are exceptions to the ratio of 3 albeit that is not the point of argument here but can't help to ponder
>
> Nevertheless, there are situations if not entirely in defilement to the above but may well be drastically different from what were based per **AISC** commentary − even though the stipulation was as ordinary and aptly as for most other applications' sake – but take that and see if it fits for generalized **CRG** interests, for instances:
>
> - For structures supporting Material Handling Operations, one can easily get a feel from comparing the dead weight of a girder against the lifted capacity in tonnage it has to carry,

and can immediately conclude that the *live load-to-dead load ratio* in normal **CRG** practice – typical **CRGs** bear an **L/D** ratio of ±15 – which is **always much too much greater than 3**

- In most Mill production processes, for which the service live loads can approach from all **X/Y/Z** directions that hardly stay still but rather move about more actively − with varying load magnitude in tow − thus (1) the load resultants are of the "travelling" kind that may "dynamically" point into "any" orientation, (2) the **L/D** ratio is a variable which for vertical load is different from that owing to horizontal load; the biggest trouble is they "always" trigger **flexural** and **torsional** events concurrently. The harsh ambience a **CRG** has to withstand and how it experiences the effect from the loads goes way beyond "*pure flexure and tension at yield*" as stated in **AISC**

- For practical matter-of-fact reasons, the cross sections of **CRG** were seldom or could never be braced at each and every load point for the loads always move about so randomly and does not stay in fixed location(s) for long

- And besides, some of the profile components could be non-compact and were vulnerable to local buckling under compression (or shear), etc. thus the application of ***"braced compact beams in flexure and tension members"*** becomes impracticable

Then a few questions came up;

(1) Aren't those inferences reasonable enough that using **LRFD** − if only **Φ** value is accurately applies − may turn out a much heavier or lighter **CRG**? (2) Or that doesn't make any difference at all? (3) Or what if it really does? …

Readers interested in the subject should "see and feel" it for themselves if any of these are true by running some calculation on their own; but *don't be in a hurry giving strong-armed answers to those interesting questions without trying*

In general practices though, it is not a good idea mixing **LRFD** and **ASD** − or switching back and forth − in the same design session unless the Practitioners didn't get confused first and then understood the pros and cons of doing so.

Anyhow, although the project-level criterion had already committed to **LRFD** load combinations per **ASCE-7 LRFD** intent, but on individual occasion, one may still need to decide if it's more (or less) practical by (1) staying with or (2) taking exception from the implications per committed **LRFD**. A decision should be made whenever allowing for **CRG's** interaction with or participation in the local and/or global framing performance evaluation as seem fit

*Nevertheless, except for situations in conflict with the Project Requirement or Corporate Standard Commitment, whether adopting **LRFD** or **ASD** should be an individual preference as to qualifying **CRG** as standalone members but do make sure the design is properly qualified accordingly*

While comparing **CRG** with **non-CRG** applications in an overview, the difference is not much in the procedures involving general structural response/stress analysis or in the methods employed for such purposes, instead it is in (1) the specific qualification process in meeting both the strength (or the stress) and the serviceability (or deflection) requirements and (2) the logistics and handling of the ancillary services needed in taming the offshoot database maintenance issues

Regardless to how it's been done or not been done per **LRFD** or **ASD**, in the context of a full-fledged qualification session for a typical **CRG**, **serviceability** issue must be attended to under all circumstances for functional and practical reasons – no excuse whether its importance was downplayed as if second banana by many Engineers

In addition to **serviceability** matter, it is equally important to keep in mind that **CRG** design assignment is never ever "completed" or "finished" without addressing both "**non-fatigue**" and "**fatigue**" issues, i.e. for meeting performance requirements, there are basically two processes underlying a typical **CRG** strength design qualification session − one for fatigue strength assessment and the other for non-fatigue design mandate

Many among us who were enthusiastic at meeting the challenge on hand know it well, but not all do. The overoptimistic and/or unprepared ones might not realize what diving deep into **LRFD** on behalf of **CRG** at the deep end feel like. The goal is simple, the hard part is in how to sort it all out and consolidate from a swamp of information; the key is in how to come up with an effective strategy geared toward separating out the data in order to meet all design qualification intents.

Herein the swamp is the mixture of *torsion*, *fatigue, non-fatigue, **LRFD** and **ASD*** and that is where it hits − since all seemed joining hands together and churning things up all at same moment.

Let's say it was already opted for **LRFD** (not **ASD**) in meeting the "**non-fatigue**" qualification intent (using applicable factored load terms with applicable load factors, etc.) as the primary process, but to complete the job, there is still a need to conduct the **non-LRFD** counterpart (using service loads with suitable load factors) to fulfill both the "**serviceability**" and the "**fatigue**" related obligations as the companion process. Kind of confusing for those not familiar with the situation but here is a clearer message yet somewhat simplified:

> *We may choose either **LRFD-** or **ASD**- based qualification procedures for non-fatigue assessment but we only need **ASD**- based procedures for serviceability and for fatigue assessment*

Even so, the two processes are as if the two sides of the same coin and are equally important in qualifying any **CRG** and its components therefore the usage of words primary and companion as the modifier here has no implication in signifying which one process is more or less important than the other

How to reach our goal of shooting for a **functional and fatigue-proof CRG** meanwhile expending minimum "data processing energy" becomes our next focus. Ideally, it is best not to duplicate the numerical efforts but to apply the same basic numerical processing logic across the board. The reason for that is quite obvious unless if not so obvious from the scenario depicted as follow:

If (1) **LRFD** were committed for General Structural Engineering purpose for the entire project and (2) **ASD** were applied only for **CRG** structures with limited subordinate project scope then the "same basic numerical processing routine" for the "loading combination" portion would have to be executed twice as we learned a couple of paragraphs ago − once for the **LRFD** non-fatigue assessment and the other for the **non-LRFD** "serviced load-based" process intended for both serviceability and fatigue strength evaluations

Regardless to whichever standard was chosen, and knowing that there would be stockpile of numbers − spread out in front of us on screen or hidden in read-only memory − if we had not carefully planned for a *data management strategy* for the worst then it could/would be a daunting "numerical" disarray to manipulate a mixed Dataset (a database term) to serve dual data management purposes: (1) factored load based **LRFD** and (2) Service load based process (although not necessary an **ASD** initiative, philosophically speaking)

As long as **LRFD** is being mandated, we could run into the same data management trouble (disarray) whether doing the task on pieces of scratch paper as in the olden days or through serious automation in this modern era. But in contrast if we opted for **ASD** scheme to begin with for the entire **CRG** project then the same "numerical" process based on service loads could be applied universally only once for all purposes, analytical or design, not twice.

Finally but not the least, if we were fully prepared to (1) avoid clutters in connection with data depository and management issues and to be (2) numerically practical then we should stick with using one universal processing routine that being the most convenient approach, wouldn't that make better sense? *To those **factored-load** enthusiasts insist on applying **LRFD**, make sure the live load to dead load ratio is three before doing it*.

In conclusion, although data management is a side-tracking non-engineering concern− as we shall see in upcoming **Chapters** − but it should be a respectable reason from that point of view, why not going from head to toes all the way with **ASD**?

4.9 Sourcing the Design Basis

In order to suitably deal with (1) the varieties of ordinary demand unique in each project and (2) those unheralded untimely emergencies that come along when carrying on with **RUPs** from scratch, throughout the execution process *as mentioned before*, all "technical" <u>eyes</u> and <u>minds</u> should stay widely open to "all things" at "all times; for good reasons.

Many **CRGs** although were born identical when new and yet could experience rations of bitterness and sweetness throughout service that were poles apart. In other words, spanning over many years, a number of those *equal-opportunity-equally-advantaged* **CRGs** would endure *different* levels of distress and be implicated in *different* **RUPs** with *different* agenda at *different* times.

Broadly speaking as to the handling of a specific **RUP** − to Practitioners being **RUP-Experienced** or **RUP-Inexperienced** alike − there is no speedier technique than brute-force ways to catch on with the essential "ins and outs," or so, one might fare better at it through a few indelible **RUPs**.

Herein the layman-termed "all things" and the "ins and outs" in extended meaning are of focus − beyond pure engineering − on assembling design basis to a specific **RUP**.

On one end of the information spectrum for technically trained <u>eyes</u>:

> Any and all official or semi-official pictorial/digitized materials – in present or past tense − such as photographs, scribbles or cartoons, as-designed working drawings, as-built drawings or shop details, repair sketches and drawings, etc., be that created from **CAD** or non-**CAD** means are exceedingly valuable asset to hold on to (in tangible format: paper or electronic) like tokens unless proven useless otherwise
>
> Acquisitions of information as sampled, as a minimum, aren't limited for appreciation of the structures' "as-designed appearance" whether agreeable with what was as-built or not. But more importantly to **RUP** on hand or future **RUPs**, they became part of the historical project asset to keep "for record" as to substantiating the basis for identifying any unusual structural features and for locating preexisting components and attachments thereof

Some of the long-gone realities could have been "*<u>undocumented</u> items*" but of structural-application's significance or "*<u>documented</u> non-structural items*" and vice versa, yet all of that might be crucial to the **RUP** engineering and detailing aspiration, and as a result prompting these initiatives:

(a) To settle on their temporary or permanent relocation, removal, replacement and/or reinstallation in case the decisions or the approvals of going-ahead with such activities were dictated by (unanimous) consensus involving diverse disciplines and

(b) To flag for special attention and to correlate the as-built(s) as much as possible with as-designed "fabrication details," which is critical for avoiding oversights in shop detailing, field interferences or misfits during repair works, etc.

And just as valuable are varieties of other non-graphics information at the opposite end of information spectrum, which more so are for the technical <u>minds</u> beyond <u>eyes</u> including but not limited to (1) original and/or latest engineering design input and (2) all applicable versions of contract deliverables revealing the historical and the latest configuration and condition of the structure, or anything useful for task at hand.

Consider the situation extremely "lucky" if all those important documents were handed over in a neat pile or happened to be in some cabinets at some convenient storage. That was perfect situation to be in, but:

> Chances are in less fortunate **RUP** encountering that good things are not always come in handily when needed. Quite likely the "most important" piece of information could be missing due to slack in bygone bookkeeping or that unaccounted for during merging or changing hands of facility ownership(s) or management personnel or else the worst due to flood or fire and whatnot
>
> Sounds familiar? But just be wary in these not so perfect circumstances, it is fairly easy to get shortchanged big time information-wise, and it does not matter whether it's a better situation prior to or worse after the contract was awarded

During **RUP** construction phase, time is always worthier than money. But any big saving or big waste in time and money hinges upon the project management quality and construction **QC** – which easily shows through from how successful the "execution sequence timing" was controlled all the way up to the "fitting precision" in every aggregate piece being installed and/or reinstalled.

And the bottom line is, <u>every component of all sizes of any significance</u> must fit **perfectly**, **timely** and **safely** in place as planned, especially if involving multiple channels of command in those non-stop running Mills. Therefore the **Current-Engineer-of-Record** (**CEOR**) should be the one **experienced** in areas well beyond *fixed engineering matters* and is always on the lookout from detailing and fabrication standpoints in maintaining the quality of all critical pieces of information whichever sources that may come from and whichever targets/recipients that may go to.

There are numerous pathways to commit (serious) money-and-time-wasting mistakes in almost any **RUP**:

> For cases in point, take situations *as (not so) trivial as the installed bolt location and dimension of a bolt hole, bolt tightening requirement, bolt slot orientation, bolt row pitch spacing, or as serious as the welding procedure or welder certification and/or inspection requirement of weld joints, material paint specification, etc.,* imagine what impact that may bring, if any piece of information were incorrect, missing or the wording in the design/material/fabrication/construction specifications were questionable yet slipped by the **CEOR** who is not up to the task in validating their accountability or failed taking an extra measurement or looking into the drawers for one more peek, then what?
>
> Likely the #1 mistake from being absentminded on the **CEOR** part would be to send for (final) engineering by "assuming" some pseudo-perfect/accurate conditions (dimensions) for **detailing** and release for shop fabrication. Sure enough, even for some of the *replace-in-kind* projects, it might be not so much in-kind after all; for instance, how about one of the bolts doesn't fit at the last minute, again, then what?
>
> As follow listed are some of the interesting – not very amusing − situations for all these overconfident or not so skeptical **CEOR** to chew on, all of these mishaps or the like could really happen; and what could be worse than:
>
> - The girder depth as shown on the "old" drawing was 24.25", which was given the go-ahead for engineering but was measured as actually 23.5" only after the fabrication had already completed, *was it the <u>Client's</u> fault?*
> - The aftermath of misinterpreting an instruction of shimming up a column by 2 inches into cutting it short by 2 inches instead, *was it the <u>Contractor/iron worker's</u> fault?*

- Supposedly a full penetration weld somehow had turned into a fillet weld or stitch weld, *was it the* *__Fabricator's__* *fault?*

- A tie-back connection piece as fabricated is shipped with configuration exactly the opposite-handed of detail as intended, *was it the* *__Supplier's__* *fault?*

- Welding a thick plate without following preheat procedure, *was it the* ***__QC's__*** *fault?*

There should be some other last-minute-mishaps similar to those as listed if we (you) dig deeper, and guess what? There is no need to point finger at anyone else; be prepared, it may *come back being* ***CEOR****'s fault*.

So before it happens in the end that ruins everything, sometimes barely in the preliminary-round of engineering, or not yet in the actual engineering-design phase but already deeply into the (engineering or fabrication) bidding process, if something critical were missing then the **CEOR** had better be on the double toiling with the Fabricator, Client Engineering, Plant Document Control or the former Engineer-of-Record to **recover** or **reconstruct** the messed-up or missing project-specifics.

And that is not all, there is always one more "surprise" after another and another; what concluded from this preliminary-round of effort would barely make up to the **first half** of what would become the complete info package – there is a second half waiting.

<u>Any unprompted situation could either be well under control or be in an opposite state; it all depends</u>:

The quantity and the quality of **RUP** deliverables although varies from facility to facility but mostly depends on constraints came from *planning, timing and outage schedule, budget, better estimating or better balancing in the demanded resources and the available resources, etc.* but more specifically on:

(a) How detailed has work scope been defined − for both engineering and non-engineering activities
(b) How comprehensive and how realistic are the current (but not the past) design input and
(c) How accurate is the account of as-built/as-is condition of the existing **CRG** and the supporting structural system, etc.

But these were merely the **first half** as explicated. An <u>unsophisticated</u> bad mistake #2 would be to pick up the pencils or press the enter key and start cranking numbers right off the blind trusting whatever comes in the "first half" without exploring and evaluating the prospects of "second half."

The **second half** of design input were (1) needed in part to authenticate the information passed on from the first half and (2) obtained to augment into those global big picture items especially when combining both "**repair**" and "**upgrade**" responsibilities or functions into same engineering venture.

And most likely, all design input would have to come from site functions, unless <u>every piece</u> of important data and useful information has been confirmed, reconfirmed and specified clearly by "someone" or that in documented form, otherwise success would be hard to come by – not only so and sometimes the immediate risk is not getting paid in time or not at all.

But to avoid potential failure in any **RUP** venture, it is always better to supplement the first half of design input, more likely **as needed** than as optional, with these pre-engineering activities:

(a) Field visit
(b) Field runway alignment survey and
(c) Field structure inspection

In **RUP**, the word "field" leads in every stage of the project; unlike the dealing with **non-RUPs** or with "brand new" or "as-designed-yet-to-be-built" structures, for which the keyword "field" rarely appears in a normal project workflow other than resolving urgent field issues that may come up during construction phase; in other words, the regular “office/desktop” engineering function rarely involves active “field” interface.

What’s in a “new” structure to most Engineers could bear a resemblance to trying out newly tailor-made fancy outfits being “all perfect.” But the fixation of mindset formed from designing “something new” intended for “everything being perfect” could fashion into an unvarying impression that, since the structure is not yet in existence, more than likely so there would be plenty of rooms in tweaking the design parameters or optimizing the system towards a configuration more amiable at Engineers’ convenience or at Client’s expenses, or both.

But, “tweaking up for perfect condition” and “hushing up mistakes through use of erasers or pressing escape/delete key” in crunch time are luxury pleas that hardly can come by in almost all **RUPs**, for which the Engineers were always dealt with:

(a) The “**as-is**” conditions for the “**repair/rehab**” aspect, and could be further obligated to take in
(b) Additional responsibility for the “**upgrade**” aspect

Gathering firsthand information from wide-ranging site activities should facilitate the **CEOR** in identifying the “good,” the “not so good” and the “worse if not the worst” circumstances more directly than sensing the like info from “Office.” In the end, a **RUP** often derives benefits from a variety of “field-driven” functions, which evidently are not that essential when designing “new” structures.

4.10 Site Visits

One shouldn’t expect every scoop of **RUP** design/detailing input information to be one-hundred percent correct/accurate at first encounter; rarely or luckily so if it does.

Whenever accepting **Invitation for Quote** (**IFQ**) on any **RUP**, it’s important to examine and validate the information as furnished was *most up-to-dated, most accurate and the most complete version* of all.

> More than ever nowadays, it is no longer “in” to selectively make or answer phone calls, read/write emails or text messaging, send/receive faxes or merely digesting the **Request-for-quote** documents without quizzing ourselves “Is that it?” Making sophisticated inquisition at the beginning is well worth spending time for

The fact is, not all Facility Owners’ Rep or Handlers are experienced or knowledgeable in defining the scope of certain **RUP**. To avoid being inadvertently misinformed, and even when no such concerns came up, a trip to the site could be the most practical way into (or way out of) the game.

> As one would expect, an ideal **CEOR** candidate should be an all-around player − Structural-engineering oriented, upskilled in handling site issues − and be Project-management conscious enough in seeing into the **IFQ** if it is (1) *missing* anything critical or significant in every aspect of Engineering and Construction − yes, in all aspects − and/or (2) *missing* the info-link with other non-engineering consequences
>
> Relatively, a trip to the site is “much more worthy” than phone calls *in the event* that whoever possesses the ultimate purchasing power happened to have given a conditionally limited work scope not quite in proportion with the actual level of difficulty or else have drafted the **IFQ** with misleading syntax not making sense or in tune with the familiar Engineering-focused Dialect, etc.
>
> Judging by nature of typical **RUP**, quite likely that (1) not every action item could be as clear, as well established or as organized just yet and (2) not every party involved could be as well trained as anticipated. It is not out of the ordinary under certain obscurity that **CEOR** may have to **donate** the Company’s own time or lend a helping hand in clarifying the project organics and

inorganics on behalf of both the Client's and the Company's best interests into formalizing the final bid spec, especially on the division of responsibility and contract deliverables

Often times an **IFQ** was initiated as if for "pure" engineering services but may turn out to be not all that "pure" in substance after the contract was awarded – just beware of surprises, again – knowing the fact nothing is perfect *as always*, many things can change or happen.

Don't expect every element registered in an **IFQ** is a firmly established order. It could explicitly or implicitly involve **CEOR's** supplemental efforts, reclaimable or not, at Company's own resource into coordinating with other team players, i.e. Survey crew, Inspector, Shop Detailer, Fabricator, Supplier, Material and Weld Quality Control, Contractor, Construction Management, Plant Safety, Maintenance and all those unanticipated players or ad hoc so-and-so outsiders who may or may not be on the same Project Team (yet) even though all may have a common objective

In certain **RUPs**, keep in mind that not necessarily every project participant from every discipline is as highly qualified or is as much an expert − in areas as to seeing the same truth or the same problem (or intrinsic fault) as we do so naturally by "our" normal Structural Engineering or Project Management sense no matter what interest each participant may stand to gain – sometimes we or *our own Clients* can greatly benefit from learning valuable hands-on experience together or with each other

Every now and then **CEOR** may need to carry extra (or much heavier workload) burden into tidying up the left-offs left off by other parties – those could be Facility Owners or their representative(s) – owing to their incompetency or inexperience

Then on occasion admittedly, we are the ones (not?) at fault; or even not so but reluctantly were held accountable *by unspoken default*; under selected states as those, rather than denying or criticizing, we might as well accept everything as is first and simply hurry up to have problem solved, and then resolve/dispute at later time for it's no use *wasting valuable time* to fight for fairness at the moment. In any case the **CEOR** should plan to pay visit(s) as often as practical as needed to the job site to firm up, re-confirm, review or renew the work scope and budget as necessary, preferably before too late into the bidding game or too deep into the execution phase

While trudging through stages of **IFQ** initiative into formalizing project scope and confirming project agenda during initial site meeting, it might as well be sensible to listen up or play dumb (or not too smart) while receiving an earful from all the (key) players: Plant Engineering, Operation, Maintenance personnel, Fabricator, Contractor, Purchasing or even our competitors, etc. Then under Plant Safety or Security's permission, don't hesitate to make special requests; or more importantly, don't turn down those invitations to take a quickie hands-on tour − whether a "quick look" from walking the plant/aisles or experiencing a "rough feel" from riding the crane

For the same reasons shared in the Industry or so generally speaking:

Many Facility Owners in on their own belief, if not already driven by serious-minded reconditioning pushes such as girder replacement or upgrade of lifted capacity in the first place then perhaps they may not have all the persuasive causes to spend (big) money soliciting **RUP** engineering services from us.

But once a decision was made to go ahead then there must be some pressing "*structural issues*" brewing if not yet boiling inside certain **CRGs** or in the runway structural supporting system, therefore knowing the most current "structural condition" of the "structure of interest" should be on **CEOR's** highest priority list.

<u>Getting to know the past and the present:</u>

Be familiar with the general condition of a runway system's performance is imperative, "see" it all from studying (1) the **up-to-date** *crane operating load specification* together with (2) the **historical** structural inspection reports that gives **valuable** clues as to where it stands on up-to-the-minute state of the system down to whenever it was *last repaired or upgraded and/or surveyed or inspected, etc.*

It is fairly common that the as given or as collected design document would have revealed not much more than the state of structure from a long-gone *distant past*. What's crucial at beginning of the **RUP** process is not to gamble based on the distant past but to entrust the sure thing based on the latest and greatest if there is or the more recent account of any **probable** structural distress the system may have suffered or accumulated since then

First thing first before kicking off **RUP's** engineering phase is, collecting <u>validated</u> design information especially for facility that is ascertained as already in deeply critical condition. If that attempt failed to fully materialize then **CEOR** could be fated to do double duty upfront or pay the price twice later on as a result of overlooking key project components that could seriously affect the **RUP work scope not knowing there is hidden cost or added responsibility, etc**.

Some of the notable agenda frequently overlooked could be concealed nowhere else but in many seemingly no-brainer types of "girder replacement program." Even an "in-kind replacement" project, which very often was mistaken as simple "copy and paste job," could leave plenty of risks leading to severe project engineering scoping headaches to many **CEORs**. Among some of the typical misses or surprises:

(a) Excessive geometric imperfections may have been "ignored" for too long; all were accumulated (since last inspection/survey or **RUP**) from various causes over time to the point that their impact to serviceability may no longer be ignored. To name a few sources or their combination: *mill tolerance, fabrication tolerance, erection tolerance, out-of-square building, out-of-square crane, offset/floating rail, inherent **CRG**/framing flexibility, residual strain due to permanent warp and rail snaking from differential thermal condition or simply mishandling, etc.* that may require higher priority attention beyond "simple" geometric imperfection

(b) It is imprudent to presuppose baselessly the induced stress from **P-delta** off the as-is imperfection is no big deal or still within the "technically" permissible amount (whatever the permissible amount could be bogus if without considering the not-so-secondary non-linear effect or when viewed from an unsymmetrical sectioned member's perspective, etc.)

(c) The girder profile geometry and/or the connection details of the original **CRG** may have been modified **inadvertently** from the as-designed or as-documented configuration (from *logically* symmetrical into *physically* unsymmetrical)

(d) On many occasions the physical existence of attachments, reinforcements, bracings, horizontal truss and lacings, jacking beams or thrust (surge) plates or portions of the components thereof could be **missing, badly damaged, added, changed or removed**. Or for the worse part from other surprises, such as *unqualified* stitch welds or weld across the element(s) in zones susceptible to shear reversal and/or tensile stress fluctuation, etc. were affixed as result of plant-sponsored internal "quickie fixes" lacking engineering backup and proper documentation but already sowed the seeds to incited *potential fatigue failures*

Finally as a reminder, before taking in any "girder replacement programs" officially as "copy job" the **CEOR** may still need to show his face on site to confirm the main reason why the replacement. It is never impolite to ask, for instances:

Was there any repair history?
When was it inspected?
Where is the original engineering document?
Was there any serviceability issue?

Be wary in some seemingly **modest RUP copy-paste jobs**, nothing would have happened in between the post-design and pre-fabrication phases. When all is well as it seems but yet real troubles could break loose at the wrong end at the wrong moment − could be in the heat of fabrication and/or construction stages − thus spending face time in site visits could be the first/last step towards alleviating future headache from these issues.

4.11 Crane Runway Alignment Survey

Whichever Design Guides, Specifications, Codes or Standards were followed or referenced in the designing of new **CRGs** – especially those **I**-shaped members – quite likely the amount of so-called "imperfection" in terms of inherent sweeps and other categories of dimensional tolerance could have been:

- Explicitly identified in the design criteria **presumably** that, any harmful effect to the structure owing to the "imperfection" and any existential threat from which were negligible. The question is has it ever been addressed and/or validated in the pertinent calculation, and/or

- Administered into the design specification according to plan, but in fact the allowed amount of "imperfection" may not be sternly observed or maintained as "trivial" in service as committed, thereby (**presumably**) the net ill-effect to the structure may have not been earnestly monitored as a result, and/or

- Technically "allowed" to dwell in the structural system and "let it be" as if some self-reliving feature however that was absorbed throughout fabrication, erection or construction provided that the measured amount against the norm were within prescribed limit (**presumably**)

The situation word **presumably**, in casual manifestation, is well meant herein for "engineering talking purposes" only. But let's say the phrase "trivial amount of imperfection" is interchangeable with the so-called "allowable tolerance" so then,

> What is the basis for allowing that amount, any calculation?
> How trivial is trivial, any calculation?
> Can static amount of "trivial" grow dynamically into "no longer trivial"?

For most applications, if based solely on recognizing or trusting an implication that the "allowable imperfection" of whatever quantity as permitted – regardless if it's reasonable or too stringent or not − then it would seem to affect more to the **QC** aspect of *shop fabrication* or *field erection* rather than a looming *engineering-based issue*, which could lead to a general reception such that:

> The ramification of any negative influence to a structural member brought over through those already pre-honored "*trivial amount of imperfections*" would have been totally defensible if that were considered "secondary effect" and so what a good excuse to just ignore it, *only when no one questions*

> Perhaps by such excuse the "*trivial amount of imperfections*" had become rightfully so regarded as negligible and justifiably **OK** under the mainstream design exemption (*even though in fact of **CRG** interest, it would be very difficult to qualify or quantify any specific effect as being trivial and/or secondary once we dig into the subject much deeper in the next few **Chapters***)

However, to those structures that had already been around for a long time:

> In spite of observing the "**permitted imperfection**" as established in the original design criteria, but symbolically, some of the **CRGs** of dire importance – while surviving years in service – would have endured incessant amount of hammering from all fronts, perhaps had deformed way beyond their natural means (or allotted endurance limit) while living through series and series of on/off live load resultant

Yet of qualitatively speaking purpose, if only trusting the theoretically permitted imperfection with no backup from actual measurement then, does that mean the state of affairs could still be considered **OK** in that regard provided the as-is or the most recently measured imperfection (rail offset and/or permanent deformation) is within the original permissible amount in terms of *leveling, straightness and/or plumbness, etc*.?

But, is it really that simple, or not so sure?

Consider the opinion as follows, which to some of us might have never taken in our normal frame of thinking at all if not explicitly pointed out:

It is always much easier to "see" or to "observe" what is considered trivial by the Codes and Standards favoring simple bending of **I**-shaped **symmetrical members** than proving it from a detailed calculation and to "look" or to "investigate" into the offbeat effect based on realistic field measurement for **unsymmetrical sectioned members**

To "see" for structural members of unsymmetrical-sectioned or even some of those **I**-shaped **CRGs**, one of the less exploited but "**cost-effective**" means for a quick account of runway condition is taking measurement from an alignment survey, and then following up as necessary with a *detailed numerical evaluation* in case the surveying result warrants an in-depth engineering validation

Being "**cost-effective or not**" is only relative depending on (1) the allotted budget and how it is done, (2) being done under what setup and (3) who is doing the survey, etc.

Cost of crane rail alignment surveys can be comparatively inexpensive when using optics or lasers – *not laser scanners* – only drawback is it requires a lock-out of the crane runway; furthermore, movement from cranes operating in adjacent runways needs to be eliminated or controlled in such a way that minimizes the effort taken to maintain a straight baseline. One of the better ways out for convenience's sake is using laser scanning for it does not require a runway lock-out, but, the cost and accuracy could be the main issues

The account balanced behind Runway Alignment Survey:

On the surface:

It seems the survey was only performed to tell a story about rail's misalignment measured locally from node to node against a referenced work line connecting two work points, or from linking the nodes to depict the rail's snaking appearance in broader sense; but

Deep down under:

It might also reveal the girder's own *hidden* alignment/flexibility *woe* as well – simply because everything to everything else is all relative – so there is a seesawing possibility that *the rail is wrecking the girder while the girder is wrecking the rail in return*

By tallying together the account behind those two tales, it sheds light on how the overall supporting system had performed as to what truly matters to structure's serviceability

The best way to "see" if indeed *the rail is wrecking the girder while the girder is wrecking the rail in return* is through "engineering review" of survey result.

Consider the case even if the subject girder might end up being replaced after all, it would still be money well spent prior to initiation of **RUP** especially if the structural system (*beyond the **CRGs***) has not been so thoroughly evaluated (by survey and other means) for years or decades. Otherwise such measure could be omitted provided that the **CEOR** or deputy has confirmation − in writing such as inspection reports − from the plant Operation or Maintenance that the runway has no alignment or serviceability issues.

With respect to what we hear or see, or what we were told, had listened to or had seen, just be cautious for a couple of important reasons:

(a) Barely "stating" the fact that there isn't any alignment issue or that of any structural concern does not always guarantee that there isn't any, unless so confirmed by surveying equipment.

Why? Not to offend anyone but ***words don't count if not on record in writing***

(b) Even if there were surveying work done for the record but not all surveyors are of same caliber quality-wise, even from applying the same technique using the same equipment but some may have provided information for other motives by that if not reliable for alignment evaluation purpose then it warrants a second opinion, and/or third opinion, etc.

Why? Not a bold statement but ***all survey results contain error to certain degree***

Yet to make do in the near term in absence of radical surveying data, the next best thing may be a rough-and-ready crane ride. It all depends on how sensitive the rider (Engineer or Crane Operator) is to any of the probable rocking and yawing motions or other modes of movement during the journey.

The recount of a crane-riding experience could be plain "pleasant," "comfortable," "fair," "tolerable" or "uncomfortable," etc., but any unusual dips, bumps, bounds, excessive leans, unusual frequent movements or unusual noises if serious enough in making anyone feel unease then there could be indications of *rail misalignment, rail snaking, structure being too flexible, imminent structural instability or foundation settlement issues*; if nothing else more important then, an investment in good-quality survey may be due.

Engineers, Crane Operators or Maintenance crews (structural runway system maintenance and crane maintenance alike) should never take on a poorly rated runway system too lightly once problem surfaces. As some of the tracking-related predicaments on the mild side, misaligned rail could:

- "Passively" wear the rail itself out
- "Actively" wear out the crane wheels and/or cause the wheels to bind and
- "Unknowingly" loosen up or shear off rail clips, etc.

Under more perilous situations in the long haul they could even:

- Set off the crane to jump track and/or
- Instigate permanent warping or tilting of the girder flanges, etc.

Besides crane/rail-tracking snags that may or may not cause serviceability headaches to Plant Operations and Maintenances just yet, but beyond the girder itself there could be other side-effects bestowed onto the immediate or nearby supporting structures/components – such as tie-back system, seat bolt or the columns, etc. − from interaction with a severely misaligned rail/supporting system.

Rivaling the flexural **P-δ** effect typified in conventional axially-loaded column design, in a sense the phenomenon of rail misalignment could be viewed as mocked **M-θ** effect for **CRG** (see **Chapter 2**,) from which the most unwanted annoyance to Engineers would be:

- <u>Obviously</u> the undue amount of torsion in **CRG** and

- <u>Not so obviously</u>, again, those plausible premature failures in the tieback system device(s) and other associated structures/components nearby

In dealing with **unsymmetrical sectioned CRG** (watch out for its **shear center** location,) just be wary of any "marginal" stresses and "excessive" rail gauge or offset displacement **unaccounted for** or **underestimated** in the original design may have implicitly eaten into the proclaimed design margin or threatened the structural integrity to certain (or great) extent. And already to the physical structure, those ill effects could exacerbate silently into undermining the serviceability if not yet started any "wrecking" commotions

Any misalignment in amount exceeded the norm should be addressed (documented) explicitly in all **RUP** for the record – the tricky part is what is the norm. Anyhow as almost always true for unsymmetrical sectioned members, it is not so apparent to the naked eyes at what stress intensity due to what quantity of misalignment could be deemed as at risk *unless someone went through a serious calculation and had done that accurately.*

No need to remind again, **CRG** is the most eccentrically loaded structure compared to loads onto other regular **non-CRG** structures; implying that misalignment of any δ amount with respect to **CRG**'s **shear center** is not only an imperfection of superficial measure but also the perpetrator in substance providing a perfect venue for **Px** and **Py** to enhance each other's flexural and torsional influences globally that could elevate the intensity of combined stress locally to any structural component at unexpected level.

Although some of the dynamics concealed behind **P-δ** are not so intuitively seen upfront but whatever that does to the structure seems to depend on the mixture and the balancing along these lines:

(a) On the overall static equilibrium conditions:

Along each **X/Y/Z** direction external to the structure, aren't we interested in, in numerical sense, how may each respective pair of **P** and δ interact? Was it linearly, nonlinearly or does it or not matter?

(b) On the load response as inherent in the section properties:

Here we go again for torsion's sake, wouldn't the blend of these key parameters **EI**, **GJ**, **EC_w** and/or **βL** predestined from certain section geometry and the amount of **P-δ** be dictated by the whereabouts of **shear center**?

On deciphering what subtly endorsed hereinbefore into our universal awareness, we should see by now, performing engineering calculation is meaningless unless we ***recognize somberly that rail misalignment is measured with respect to the shear center rather than from the installed rail centerline or girder web***.

Although what pointed out might not make much difference to symmetrical sections but, remember, it always does to unsymmetrical sections. Therefore for good practice's sake and a peace of mind after acquiring the misalignment measurement from a creditable survey, for which the Engineers should always:

- Calculate the induced flexural and torsional stresses; for which always make sure that **shear center** was correctly located in the first place, and also

- Make sure each respective stress category does not elevate too much into risking breakdown from yielding and buckling if not already suffering any consequences from **metal fatigue** yet

Some of the not-so-easily-convinced Engineers may find it challenging to settle on the fact or may refuse to agree with, but, it is all so true that the warping normal stress from rail misalignment by calculation, even for seemingly ***insignificant*** *quantity, could amount to* ***50% or more*** *of the regular flexural bending stress as proven in actual design examples (see* ***Examples, Chapter 6****)*

Due to the **3-D** load nature, we could safely say that no **CRG** could escape the torment from rail misalignment once it took place (temporarily or permanently) and it's only a matter of how severely would the **CRG** have suffered and how much longer they could stay being trouble free

At certain **X/Y/Z** depending on (1) the local detailing feature and its distance to the **elastic centroid** and **shear center**, (2) what load and/or load combination is/are in effect and (3) the realistic measure of rail misalignment, etc.,

Both flexure bending stress and warping normal stress would always act along the same strand of longitudinal fiber(s) that on one hand they could but not necessarily cancel out at a given instant, but on the other hand they may (or may not) be additive only few moments later. Guess what could be the problem?

In a worse scenario, but not uncommon, back and forth they cancel then they add up and through a number of stress fluctuation cycles, it ends up putting enough risks into initiating base metal cracks or furthering the growth in existing cracks, or enhancing to a point amplifying the probability of local buckling or material yielding due to presence of excessive compressive stress

The most intriguing and unexpected phenomenon or "flaws" can be cooked up from natural load response owing to excessive **shear center-rail** offset dimension alone if the **shear center** was incorrectly located to begin with; furtherly on account of unusual section properties subsisted in unsymmetrical section geometry, with which by proper calculation, we should be able to "guess" if there existed any engineered "flaws" or not *with or without rail misalignment*

The "flawed" event would take shape whenever the damaging potential inbred in the warping tensile stress overpowers the "protective shield against metal fatigue" inherent in the moderate amount of compressive stress held out in a flexural compression zone (just read this paragraph a few times if confused)

Many Practitioners − who have not perform calculation in this/that regards − would have never expected the fact that a compression flange under flexure can be dwarfed by warping normal tensile stress induced by torsion

So much so be however the "flaws" were brought forth through whatever means, but in general, the hidden danger is, these "flaws" or the propagation of "flaws" could materialize even if the calculated stresses (ranges) are **well below yielding and/or at very low live load loading-unloading cycles** – seemed like a preposterous speculation but it's not, the *only way to prove the truth is by calculation that's done correctly*

Therefore any modest amount of rail misalignment could in part advance an answer to what had bewildered many Engineers the most upon reading the inspection report or looking at the troubled **CRG** trying to figure: Why a **CRG** system (sometimes not very old) is as adequate as designed "on paper" but would suffer chronic (or unexpected) damages much sooner than expected. *Why? The answer is the girder perhaps had never been adequately qualified to begin with*

The criteria employed in grading a runway's status, either "good," "fair," or "poor" should be based as much on review of hard numbers as possible, if not from surveying but at least from a close up inspection (and that should never be on human's sensitivity over crane rides alone.)

But how could anyone pinpoint the original cause/source of excessive misalignment?

Is it from the rail, the crane, the girder, the tie-backs, the columns, the foundation or flexibility of the building system?

Without backup from **credible** survey and/or inspection data there would be no practical means to rely on as to figuring out the **relative** "over-gauge" and "under-gauge" among various **CRG** components, without that let alone **guessing** where are the trouble (hot) spots or evaluating how has the system endured or figuring out what to do to rectify the problem, etc.

What had been advocated is;

Don't point fingers at the wrong guys (we mean wrong causes)

Obviously the purpose of rail alignment survey should not be limited to meeting **CMAA-70** runway alignment tolerance alone or those specified for any other purposes.

It should include "detailed" planar and/or elevation offsets with reference to as many "meaningful work points" with interfaces as required with edge of rail, girder components and columns or even roof trusses and foundations, etc. No matter what, *never fix "work point" off any targeted objects that were damaged, out of shape or had tendency to move or be removed or be relocated*

The truth being, after years of services even with unintentional slacks in maintenance or plain abuse if there is, it would be hard pressed for any rail system in any given facilities to stay perfectly aligned forever expressly under high cycles of frequent trolley bumping/swinging/dragging and crane loading/unloading actions *–in areas where materials are being constantly moved in and out of facilities such as Shipping Bays*. Therefore the results from such survey are invaluable for **CEOR** in developing:

- Additional "loading" criteria for **CRG** stress analysis due to rail offset, the question is of what amount
- Basis for layout and recommendation of rail alignment offsets, global calibrations and/or local shimming for **CRG** and/or other supporting elements
- Additional work scopes on the entire structural supporting system beyond **CRG, etc.**

4.12 Runway Structure Inspection

The responsible branch overseeing Runway Structure Inspection Program varies from Facility to Facility. It could be more of a Plant Management/Structure Maintenance/Reliability's area of focus rather than a pure Engineering function whether the work was outsourced or not.

There is no set rule in how to present the inspection results as long as the story told makes sense from facility maintenance management and planning-scheduling's point of view. However, in order to make rational sense to Engineers, it would be more helpful if the finding details were documented, organized and formatted for **RUP Engineering Assessment** purpose at the very least. But even so, the actual level of help to a specific facility might still be limited unless:

- The established Structure Inspection Program had been implemented on longer term basis and that be even better if it's *condition-based*. To those Facilities if the inspection program was not regularly scheduled then, as minimum, there should be inspection records that were kept up-to-date within a reasonable time period prior to the active **RUP** initiative, and
- For purpose of facilitating a quick/in-depth assessment − only if attainable − the accumulated long term inspection findings and/or maintenance records are better be organized following consecutive order when those events occurred; by way of proper *database links* out of which one could unfold an untold story in no time, or else even if lacking intentionally linked data but through chronologically maintained paperwork and associated deficiency location plans, it should suffice for carrying out rapid evaluation revealing whether the structure was in a "fair," "poor" or "good" condition, etc. and more importantly for how long had the structure been in that state

Otherwise an up-to-the-minute inspection might be due (again, the final report should be properly documented and formatted) and such inspection should be strongly recommended by the **CEOR** who should try the very best to motivate whomever opposes

Both Structural Inspection and Rail Alignment Survey − if executed properly/accurately then − are equally important to **RUP** project engineering function through each of their own trait and can complement each other in assessing the general structural condition of a **CRG** system.

RUP (structure) inspection is different from rail alignment survey in many aspects. Deliverables from survey have much to do with rail/girder work points, baselines, direct/indirect measurements and component geometric relations, etc. Deliverables from structure inspection entail observed deficiency findings (mainly) of **CRG**, its local components and as required, the nearby supporting structural system.

The quality and quantity of inspection data being compiled in the reports should not be limited for reason of fulfilling safety audit obligation alone; they should include *sufficient quantitative details*, which not only is convenient for immediate performance diagnostic and assessment purposes but also suitable for producing database-linked historical report ready for future **RUP** evaluation use.

One of the not-so-optimistic facts of matter is, the contents in many inspection reports were found not on par with what should have been, or that in some ways were dispersed more so non-engineering driven or not very management friendly; for example:

Many boiler-plated reports appeared full in outward appearance but what could make it better is furnishing a showpiece summary facilitating instant snapshot to make a quick appraisal with

A well-prepared *Report Summary* is a great feature from management perspective that provides ample insight in short takes without reading through the full report. It helps even more if it comes with a well-thought-out *deficiency location plan*

A report would not be of much help to **RUP** intent if merely bloated with numerous look-alike template sheets without divulging "general notes," or else so ballooned in sheer volume inundated with pictures missing proper logical arrangement and identification tags or important annotations to correlate with itemized findings, etc.

Clearly, boiler-plated reports as those were not engineering-driven and not database-ready, which may excel in sizes and looks yet leaving plenty of rooms for speculating but not telling a true engineering-friendly story. One could peruse many pages of log of events to realize most were a long way off for purpose of **RUP** project engineering, executive summarizing, repair-cost estimating or management decision supporting functions, etc.

Again, different inspectors (from different inspection teams/companies) may come up with different report styles and/or content organizations on different principles. But preferably, **RUP** inspections should be very much **engineering driven** with results **database ready**. At the least **RUP** inspection should be:

(a) Performed or led by "quasi-blue-collared" Structural Engineers experienced in looking for troubled spots and deciphering whether certain symptoms are of indispensable value or being insignificant, etc., or else inspection works should be carried out or assisted by Inspectors schooled with the said engineering perceptions; and for the better, the "Inspectors-Engineers" or "Engineering Inspectors" should be somewhat razor-sharp at organizing field notes and taking critical measurement

(b) Performed up close from walking or riding the crane along the runway, on **JLG** or platforms − instead of willfully peeking from afar through binoculars or naked eyes

(c) Most importantly, performed only by those already safety trained (**OSHA** approved and/or plant-sponsored programs,) properly **PPE** geared, physically prepared for taking on reasonable nuisance from dust, dirt, loud clatter, heat, cold, rain or shine and preferably those with no fear of height, etc.

The in-service performance summary of an existing **CRG** system would be much better outlined "right to the point" in an inspection report, so that anyone reading on the receiving end could immediately make out the seriousness of structural condition by the summary page(s) alone − without having to flip through pages after pages − but easier said unless the task(s) were carried out with a thorough engineering review, safety risk analysis of the condition and the "deficiency level" of each individual inspection finding, and so on.

From a safety-risk evaluation viewpoint, some of the "insignificant" deficiencies might be arbitrated as lower level risk and branded as "for record only" while the more "serious" ones might be classified into higher priority status for follow-up action that may warrant *"near term monitoring," "immediate attention," "requiring in-depth engineering evaluation," "requiring immediate repair" or even "safe shutdown"* whichever action(s) deemed appropriate.

<u>A subtle tip:</u>

It would appear more logical if each individual finding was tagged with abbreviated attributes or <u>multi-tiered</u> **data sort key** that tied in with (1) the assigned safety-risk category index and (2) recommended management or engineering resolution, and better yet, a final tallying of these attributes could prime up an advanced clue to the management or decision makers on the general structural condition up front without having to fumble through or dig "blindly" into the thick of inspection report.

From an engineering standpoint on ramification from deficiencies including but not limited to *railheads, rail clips, hot rails, girder seat bolts, attachments, tiebacks and bracings, cracks in weldments and base metal, etc.* each individual **CRG** should be evaluated on a case-by-case basis prior to starting any serious "engineering" or "repair" activities.

As mentioned earlier, **the complexity embroiled in handling structures of this caliber − having unsymmetrical sectioned profile − was inherent in the atypical relationship between** applied loads **and** profile geometric features**.**

> As the coverage on various profile geometry-related issues had run its course on **Open Sectioned Crane Runway Girders with Arbitrary Profile Geometry**, naturally, next up should be on definition of applied loads; but prior to doing that, one may wonder how in a nutshell to tell quickly if a structure was (not) properly designed without making any calculation:
>
> The simplest way to "see" that is through **Runway Structure Inspection**
>
> Even though in general, most of us would have been self-contained in deference to show professional curtesy with full trust that the as-given section geometry of an as-fabricated **CRG** is a genuinely qualified *configuration*, which should have been rightfully blessed by well-intended design practice; thus with all due respect, it shouldn't and cannot be changed or be questioned by the time the girder had been erected in place, but, is that so?

As to the design of any given **CRG**, despite the applied load magnitudes were accurately defined and set for analytical purposes, but for which, what if the section geometry including some connection details were *unsuitably configured* from a "seriously flawed" analysis-design process to begin with?

> The fact is, "flawed design" can seriously *disfigure* the structure

Whether we see to that fact or not even if some Readers might not believe what a "seriously flawed" design could do so much harm to an ill-fated **CRG**, hereinafter it takes a real-life story be blatantly told to win over those who are skeptical through facts of what could and did happen. The come about was so dramatic that no Desktop Structural Engineer would have ever believed the level of damages a "flawed design" can cause unless personally getting involved in the "inspection" and witnessing the drama firsthand.

Here it Go:

During the inspection of a ±mile-long runway structure there the Authors came across many thrust-plated unsymmetrical-sectioned **CRGs**, many of which bore similar pattern of cracked welds in the base metal; some cracks occurred in multiple zones within the same girder span where the top flange meeting the web stiffener, and several cracks had already extended diagonally down the web towards the bottom flange. The average horizontal crack was ±42" long, which came to be 7% of the typical girder length of 50^{ft} = 600"

> As noted in the inspection report, most cracks took place in a supposedly compression zone but failed as result of inherently low *shear fatigue strength* at the weld joint. Similar findings had appeared in more than ±70 other girders in the same building and all having identical section configuration bearing similar symptoms in general
>
> From an engineering design viewpoint, *once the crack "tore apart" the top flange and web, the shear flow through the cracked joint is interrupted immediately*. The behavior of the girder becomes unpredictable because there would be shear stress concentration developed at the terminal edges of each crack and it is doomed to propagate over time
>
> As condition was deemed so serious then, remedial action was recommended and that should have taken place **–** even with **the cosmetic kind** of repair **at best –** but none

Fast forward to two years later, what was unpredictable did get worse much as expected. The individual horizontal crack had either propagated further on its own merits or some had joined up with other cracks over multiple zones into a single tear as much as ±240" long in few cases, which came to be 40% of the girder length

> Under continued operation lacking remedial actions, some of the webs were buckled in part and bulged out of (vertical) plane that can no longer provide proper propping against the bottom of top flange because detachment had been coined in between
>
> In some of the more severe instances, the *disfigured* girder web had been worn out/off exposing a "**V**" groove on top where the crane rail/top flange was driven to span over and act as bridging. Missing solid support beneath the rail/top flange, its deformation would grow with each crane passing over
>
> As crane rail being *disfigured* beyond elastic limit and zigzagged into a permanent "**Z**" creating a local elevation differential of several inches over time, it became a tripping hazard and on many occasions loud booms can be heard from a distance as crane wheel bumping too hard over the "**Z**" obstacle. *The production-operation was finally interrupted at a fateful event when one of the overhead cranes jumped the track and felt onto the ground*

Situation like that is not widespread but certainly a unique example to show how dangerous and how bad it could get if our design is flawed. Unfortunately distresses in **CRG** structure in many instances took too many years to be exposed or, in other words, that could be too late to establish a simple fact: *The original design was seriously flawed*.

In the process there is no need of checking the engineering calculation, there were ample evidences to prove it through Runway Structure Inspection alone.

4.13 Crane Wheel Loads

Establishing **RUP** design input info is a multi-function process. In summary, the project-specific design input loads could be consolidated as applicable from sources such as:

- As-built design documents (criteria)
- Plant engineering and maintenance/operation information
- Crane/trolley specifications and lifted capacity
- Latest rail alignment survey and
- In-service structural inspection data, etc.

For the best interest of **CRG Engineering** to all Structural Engineers alike, the most important piece of information should be the **Crane Wheel Loads**.

> In **CRG** design, it is common to be dealt with series of wheels arranged at equal/unequal spaces; and on (rare) occasions whereby each wheel could be loaded at unequal magnitude also. What truly hits home is in the lively setting, in which not only the load node under each wheel is always *in transit* during operation but also the *load resultant vector* may point to an arbitrary direction in the **3D X/Y/Z** space

Although the situation as said seemed fairly easy to comprehend, yet the experience in the "handling" of which might compel a sense somewhat confounding if not properly organized ahead (see **Chapter 8**.) But rest assure for the moment, what's more important prior to the "handling" is to get a good "handle" of the normalized magnitude of these loads.

To normalize the matter, a generic wheel load resultant supposedly in **3D** could be resolved into any number of components fitting respective global orientation as chosen. Ideally each component's orientation would have conveniently (or purposely) been lined up with the dominant girder element – flange or web − for easy referencing and for structural analysis as well.

These components are:

(a) **Y**-load – pointing (per adopted sign convention) either along or against the gravity axis:

An upper-bound magnitude is established as the *maximum* wheel load (**MWL**.) Its static version is the *greatest possible* load amount taken from among the group of wheels bearing on the crane rail, which is calculated from (1) the dead weight as an integral of all moving equipment including crane framing, trolley, hoist, etc. plus (2) the design lifted load capacity. To account for dynamic effect from hoisting movement, an impact factor is applied to **MWL** as add-on

(b) **X**-load - acting along with the trolley movements:

Known as side thrust or lateral surge load or herein as **Lateral Thrust Load** (**LTL**,) it could act in reverse along +**X** or –**X** becoming the most direct contributor to fatigue failure. Its magnitude may be controlled by the lifted load capacity alone or that combined with the weight of trolley or from all or part of equipment operated on the crane rail

(c) **Z**-load induced along +**Z** or –**Z** from contact friction of rail against the drive wheel(s) or of all wheels, collectively known as the traction force

MWL being the focal point herein, it is the most critical piece of information for **CRG** load response analysis. That is why for comparison purpose and for handling convenience, both **X**- and **Z**- loads were normalized from **MWL** into respective fractions indicating the relative order of magnitude.

In most applications **MWL** was given ahead of time. But before using it for structural analysis, the **CEOR** should go through with other "project-supporting design input" and verify what might be **redundant** or **missing** in case there is mistake.

Typical crane wheel load-related information helpful for structural engineering use may include:

(a) Building framing layout and **CRG** (shop) drawings
(b) Drawing/schematics and specifications for each individual crane
(c) Clearance diagrams and crane bridge wheel load diagram for each crane and
(d) Applicable modes of operation: single crane and/or multiple cranes, etc.

At the initial stage of **RUP**, it shouldn't be surprised when given only the bare minimum info such as wheel load magnitudes, dimensions or spacing between a number of roughly drawn circles and nothing more. But if information were sufficient for structural engineering purpose then there should be no need to regenerate the **MWL**.

The rationale in figuring out crane wheel **Y**-load is not much different from calculation of dead load or other common forms of live load.

However, in some cases the as-given **MWL** may appear questionable or unrealistic; should that be true then neither would its derivatives (lateral thrust load and traction load) be reliable.

> This situation could happen more often when the crane bridge, trolley, lifted load capacity and/or the overall structural facility itself had been modified, upgraded, de-rated or degraded (several times over) from changing of usage function or equipment supplier or facility ownership, etc.
>
> For that reason it would be worth the while to double check the **MWL** magnitude whether it's given by Client Engineering or Crane Manufacturer, better just do it than be regretful afterward

Demonstrated as follows are simple crane wheel load examples (in that the subscript 1, 2 applies to parameters appearing in Example 4.1, 4.2, respectively)

Example 4.1

Given: Mill crane #1, bumper spacing = 21^{ft}, bridge weight $\mathbf{W_B} = 60^k$, bridge span = 75^{ft}, 2 wheels on runway spaced at 15^{ft}, **equal-wheel-load distribution alone Z**, lifted capacity $\mathbf{P_C} = 20^{Ton}$, trolley weight $\mathbf{W_T} = 10^k$, 2 trolley wheels spaced at 12^{ft}, single driving wheel.

Required: **MWL**, **Total LTL** and traction force

Solution:

R_{b1} = bridge reaction at each end due to only the bridge weight
$= 60^k / 2^{\text{ ends}}$
$= 30^k$
W_{t1} = sum (trolley weight + lifted weight)
$= 10^k + 2^{\text{ k/T}} * 20^T$
$= 50^k$
f_{tlp} = trolley lifting position factor
= (75' – 12' / 2) / 75'
= 0.92 max, or
= 0.08 min
R_{t1} = reaction for extreme trolley lifting position
$= W_{t1}$ * maximum (f_{tlp})
$= 46^k$
R_{max1} = maximum bridge reaction on girder
$= R_{b1} + R_{t1}$
$= 76^k$

For equal-wheel-load distribution into 2 wheels:
$MWL_1 = R_{max1} / 2^{\text{ wheels}}$

$= 38^k$ per wheel

Individual vertical wheel load:
$WL_{1,1}$ = load for wheel 1
$= 38^k$
$WL_{1,2}$ = load for wheel 2
$= 38^k$

On computing **MWL**, be prudent to verify if the condition of "equal-wheel-load distribution" applies. This is mostly true for cranes having not too many wheels spaced at relatively closer distance between wheels, also, it is only true on assumption that the end truck is stiff enough to be treated as a *true rigid body*; otherwise the "wheel load distribution" or "wheel load sharing ratio" may depend on:

- The weight of the crane components and attachments and
- Their balance as being more concentrated or more distributed and also the general arrangement in **3-D** space

Prior to the Black book edition for many years, **AISC** had specified *a minimum of 25% increase of **MWL** on crane-induced impact for structure supporting cab-operated traveling cranes and respectively a minimum of 10% for pendent-operated cranes*.

> As per **AIST Tech 13**, **unless specified otherwise** in applicable Design Standard or Project Specification, 1.25 vertical impact factor for Mill cranes would be applicable to all wheels (in typical applications, impact does not apply to multiple crane operating in series)

$C_{i,1}$ = mill crane vertical impact factor * MWL_1
$= 1.25 * 38$
$= 47.5^k$

Per **AIST Tech 13** if not mandated otherwise, the traction factor applied to **MWL** as design *traction force on each rail may be taken as whichever that governs from the two sources*:

- *20% from only the drive wheel loads*
- *10% of all wheel loads*

Traction force $= 20\% * 1^{\text{drive wheel}} * MWL_1 / 2^{\text{wheels}}$
$= 3.8^k$
or $= 10\% * 2^{\text{wheels}} * MWL_1 / 2^{\text{wheels}}$
$= 3.8^k$

Next onto the "lateral thrust" along **X**-axis:

It is true − both in theory and in actual operation − that thrust load could be applied either *unidirectional* or in *reverse coupling*, which depends on the tracking situation involving *crane framing-end truck's squareness, crane wheel alignment, crane rail alignment and girder stiffness against lateral movement*

To a simply supported straight member under flexure, *unidirectional load would cause single curvature while reverse coupled forces would cause double curvature*

> Granted the treatment to reverse coupling would engage much trickier math, which would complicate the structural analysis and design qualification more than anything else

But relatively, unidirectional thrust induces greater amount of lateral deflection and bending than reverse coupling does thereby would have done more serious physical damage to the **CRG** structural system compared to that from the fancier reverse coupling anyway. Therefore when viewing from both non-fatigue and fatigue design perspectives, the **CRG** structure should be adequate if it could withstand what imparted from unidirectional thrust alone

Since the weight of trolley together with its lifted loads (rated capacity) are supported by the crane bridge, which is spanning the full crane aisle that has a longitudinal bridge axis running parallel to the global **X** direction, with each end of the crane bridge resting on a discrete **CRG**, naturally any **X**-oriented side thrust loads being passed on from any active load-imposing contestants should **eventually** be shared by both girders, one on either side of the aisle

The big question is:

What is the dispensing ratio, is it always 50-50?

Prior to apportioning thrust loads into the respective wheel group on each girder, one must obtain the **full** integral amount of "**Total side thrust**" or come up with the full amount "**Total LTL**" attributed from the crane to begin with

Usually **Total LTL** has two ingredients: "Load source/sum" and "load multiplier"

"Multipliers" also known as "thrust factor" that can be viewed as "equivalent static load factors" or "dynamic load factors." Several categories of load source/sum were recognized in various **CRG** applications in that each specific load source/sum category is associated with an applicable load multiplier

A "fundamental load multiplier" or "basic thrust factor" is applied specifically to the most dominant load sum or the most dominant load source − which in no doubt is the lifted load capacity **Pc** − and then various factors deduced from that could be applied to supplementary patterns of load sum or load source. By applying several unique percentage values to the respective load sum categories, one could obtain a range of "**Total LTL**" values for design consideration

The dominant fundamental load factor (multiplier) is given in the well-recognized Design Standards such as **AIST Tech 13** or the adopted Project Specification. Its value varies with the distinctive type of crane; i.e., if designating the dominant factor or multiplier as $\mathbf{f_T}$ then the **Total LTL** for design use is commonly the controlling value from these three conditions:

$(\mathbf{f_T}) * (P_C)$
$(\mathbf{f_T} / 2) * (P_C + W_T)$
$(\mathbf{f_T} / 4) * (P_C + W_T + W_B)$

If in this example the given $\mathbf{f_T} = 0.4$ – *read on for further discussion on this subject later* − for Mill crane application then:

- For lifted load
  Total $LTL_{1A} = 0.4 * 40^k$
  $= 16^k$
- For the combined weight of the lifted load and trolley;
  Total $LTL_{1B} = 0.2 * (40^k + 10^k)$
  $= 10^k$
- For the combined weight of the lifted load and crane weight;
  Total $LTL_{1C} = 0.1 * (40^k + 10^k + 60^k)$
  $= 11^k$

Complementing **MWL**, the **Total LTL** plays equally if not more important role in all **RUPs**. The actual definition of load sources and multipliers used for **RUP** should be application-unique. Obviously the "load factor" needs to be verified with Applicable Codes/Guides and be concurred with the Facility Owner. The next example would calculate the wheel load using an *uneven wheel-load distribution*

Example 4.2

Given: Mill crane #2, bumper spacing = 22^{ft}, bridge weight $\mathbf{W_B} = 70^k$, bridge span = 75^{ft}, 2 wheels on runway spaced at 16^{ft}, **4:6 wheel-load distribution along Z**, lifted capacity $\mathbf{P_C} = 25^{Ton}$, trolley weight $\mathbf{W_T} = 12^k$, 2 trolley wheels spaced at 15^{ft}, single driving wheel

Required: **MWL**, **Total LTL** and traction force

Solution:

$R_{b2} = 70^k / 2^{ends}$
$= 35^k$
$W_{t2} = 12^k + 2 * 25^T$
$= 62^k$
f_{tlp} = trolley lifting position factor
= (75' – 15' / 2) / 75'
= 0.9 max, or
= 0.1 min
$R_{t2} = W_{t2} * (\max f_{tlp})$
$= 55.8^k$
R_{max2} = maximum reaction
$= R_{b2} + R_{t2}$
$= 90.8^k$

For 4:6 wheel-load distributed into 2 wheels:

$MWL_2 = R_{max2} * 6 / (4 + 6)$
$= 54.48^k$
$WL_{2,1}$ = load for wheel 1 = MWL_2
$= 54.48^k$
$WL_{2,2}$ = load for wheel 2
= 90.8 – 54.48
$= 36.32^k$

If calculating the maximum vertical impact load, traction force and the **Total LTL** in ways similar to that for Example 4.1 then,

$C_{i,2}$ = Mill crane vertical impact factor * MWL_2
= 1.25 * 54.48
$= 68.1^k$

Traction force = $20\% * 1^{drive\ wheel} * MWL_2 / 2^{wheels}$
$= 4.54^k$
or = $10\% * (WL_{2,1} + WL_{2,2}) / 2^{wheels}$
$= 4.54^k$

The total side thrust ... shall be the greatest of:

- For lifted load;
  Total $LTL_{2A} = 0.4 * 50^k$

$= 20^k$

- For the combined weight of the lifted load and trolley;
  Total $LTL_{2B} = 0.2 * (50^k + 12^k)$
  $= 12.4^k$
- For the combined weight of the lifted load and crane weight;
  Total $LTL_{2C} = 0.1 * (50^k + 12^k + 70^k)$
  $= 13.2^k$

4.14 Lateral Thrust – The Probable Controlling Source

Notice as demonstrated in the preceding examples, one can observe a condition likely true in most applications. Visibly, unless the weight of the crane bridge equipment $\mathbf{W_B}$ and/or that of the trolley $\mathbf{W_T}$ are **unusually heavy**, the controlling value of **Total LTL** would have been governed by the pure "lifted load $\mathbf{P_C}$" i.e. with zero contribution from either the crane bridge or the trolley.

But is that always so?

Technically, regardless to whichever individual load term or combination of terms that may have conclusive control over the *design thrust load*, it would be much more convincing that each partaking parameter $\mathbf{P_C}$, $\mathbf{W_T}$ or $\mathbf{W_B}$ could do the numerical talking for themselves through clear-cut arithmetic.

For furthering a curiosity, we can delve into the probable scenarios that could play out on all the generic **Total LTL** values, each from which given a subscript into a collection {$\mathbf{LTL_A}$, $\mathbf{LTL_B}$ and $\mathbf{LTL_C}$} to be based on a common basic thrust factor for lifted load = $\mathbf{f_T}$ then the following expressions should be valid per previous examples regardless to the value of $\mathbf{f_T}$:

$LTL_A = f_T * P_C$
$LTL_B = f_T * (P_C + W_T) / 2$
$LTL_C = f_T * (P_C + W_T + W_B) / 4$

By considering some of the most fundamental inequalities with comparisons among all **LTL**s one could easily deduce into the parametric relationships and solve for the corresponding expressions in terms of $\mathbf{P_C}$, $\mathbf{W_T}$ and $\mathbf{W_B}$ into following three cases:

Case 1: if $LTL_A \geq LTL_B$ then
$P_C \geq W_T$

Case 2: if $LTL_A \geq LTL_C$ then
$P_C \geq (W_B + W_T) / 3$

Case 3: if $LTL_B \geq LTL_C$ then
$P_C \geq W_B - W_T$

Interestingly the logics implied in all three cases could be played around and derived into the conclusion that in order for any one value among $\mathbf{LTL_A}$, $\mathbf{LTL_B}$ and $\mathbf{LTL_C}$ to become the upper bound controlling the lateral load design value, there should be one and only one of these conditions to be met:

Condition 1: LTL_A controls
If both Case 1 = True and
Case 2 = True

Condition 2: LTL_B controls
If both Case 1 = False and
Case 3 = True

Condition 3: LTL_C controls
If both Case 2 = False and
Case 3 = False

4.15 Lateral Thrust – The Certainty of Uncertainty

To **CRG**s providing crane loading/unloading support function in typical Mills, *lateral thrust* ***Px*** *is set off as result of trolley's forward-and-backward movements along the* ***X****-axis*.

Knowing the **X**-load/force is concentrating at an interface where the stationary Crane Rail meets the moving Crane Wheel, so if isn't for such interaction then lateral thrust would not survive "actively" as a standalone entity. Inherently **Px** would have to synchronize its existence with vertical load, **Py**, which could either be the dead weight of the overhead crane alone or that with the addition of live (lifted) loads

In other words, *there would be no* ***Px*** *if isn't for* ***Py***

Other than the direct impact from trolley hitting its bumper, lateral thrust could also be a frictional consequence deduced from several non- impact natured loading scenarios (see further opinion coming up later.) Yet to dig deeper beyond common understanding, it is rather difficult to quantify such somewhat bewildering effect precisely if only relying on empirical ruling devoid of field testing results as backup.

The lateral thrust loads appeared in **Examples 4.1 and 4.2** were simplified by applying an equivalent static ($\mathbf{f_T}$) factor to **Py** in ways similar to those design examples being handled elsewhere.

Whether viewing with a pure engineering sentiment or from applied science viewpoint, lateral thrust (as of this writing) is perhaps the most "uncertain" piece of **CRG** loading information for lack of practical means that one can resort to backing up the true value of $\mathbf{f_T}$.

Taken by the somewhat hazy definition of $\mathbf{f_T}$, it sure paves a perfect path leading to design loopholes or excuses (if not) for some no-winning argument's sake

No matter if disagreeing on the offense or endorsing on defense, or else when taking no particular stance (in office or in courtroom,) the fact is some could vehemently critique that $\mathbf{f_T}$ being assigned is way too high and/or unrealistic while some others would counter it as being too low

Anyhow, there shouldn't be much dispute in "recognizing" that the Industry at large is in need of a consolidated $\mathbf{f_T}$ based on testing results. On the matter say it simple even if someone eagers to take charge of, but, the real issue is how to do it and who is willing to do it

Nonetheless in real world relevance, lateral thrust ± **Px** is always in presence of ± **Py-δ**; thereof by permutation, they had mathematically become the **most destructive cause** to "runway system" considering the combined damaging effect that could impart onto (1) the **CRG** itself and its common medium attached thereto and to (2) the immediate supporting system nearby and beyond including columns and even the foundation anchorage

To most Practitioners then, the "technical uneasiness" in lateral thrust's definition and its application in design could be manifold:

- The "design-based mystery" − on both theoretical and practical matters involving "load source" as to its formation, formulations and justification, its quantity and/or how physical could it get, etc.

- The "engineering/analytical focus" − on application in relationship with concurrent rail-float being broadened into the "load nature" that it does act out along (**±**) opposite senses, etc.

- The "load consequence" − in recognizing the fact as load switches sign, it could induce tensile stress fluctuation and/or shear stress reversal as an unbridled contributor to fatigue failure in many critical structural components if the matter were not seen into properly and thoroughly

One could safely see the fact that **Px** could not do harm to **CRG** by itself alone without an accomplice, **Py**. Although the structural responses drawn from the "**Px + Py congruent**" could be isolated numerically as if each being an independent loading event, but what **CRG** typically feels or sees into itself is the constant scoring from an inseparable source-consequence of the load resultant, which is a variably oriented vector sum combining both **±Px** and **Py** (with or without ± rail floats) encircling a truth to the fact about the **Shear Center.**

*Notice that, without considering rail floats, already (**+Px** + **Py**) and (**-Px** + **Py**) represent two distinctive vectors*

To dispute optimistically:

Not every **CRG** during its service life span would experience the most extreme design loads as estimated and the most detrimental load combinations as specified, or would it?

Or, not necessarily the fateful fatigue failure event would materialize to every **CRG**, correct? And if it does then, would lateral thrust be the principal offender?

Yes or no but see if it is reasonable to press on further:

- Should any **CRG** structure be rightfully "penalized and punished" by metal fatigue alleging lateral thrust's involvement then, the "quantity" given from the "punishing source" should better be defined fairly, squarely and be "technically persuasive" with no hidden suspense, otherwise how could we prove to those skeptical parties including many among us?

- Be that realistic or not, but what is the **true maximum design thrust load**, after all?

- If there is a way, could the load be substantiated from field inspection/test results or conceivably derived through **solid numbers**?

Probable consequence from using any solid number:

Not knowing whether if the design thrust value based on a specific $\mathbf{f_T}$ factor (as a percentage with respect to the **MWL**) were too little, too much or just right, by whichever that is etched at least on paper, if we have doubts that $\mathbf{f_T}$ is too high then, should we just blindly accept it as an **A-OK** no-question-asked value? Or should we not question before we let it break the (supporting) structure needlessly?

Interestingly enough from looking back on the thrust load subject's development over many decades; the quandary is in the fuzziness in how the historical $\mathbf{f_T}$ factor was defined. It appears that the allotted values of $\mathbf{f_T}$ factor − at one point or another − had not been standardized among different (editions of) Codes, Standards or governing project design criteria

In **CRG Engineering-design** advancement through eras gone by − singling out no particular time frame − the mandate of $\mathbf{f_T}$ factor could be confusing on occasions; for it might remain as if established firmly for a while but then in due course could be updated afterward even for the same set of Design Criteria depending on which edition of the criteria governs as to what, whom, where and when the application makes (not the best but) better sense

Even though – in Authors' opinion as of this writing − such technical inconsistency or uncertainty as said (may still) exist, the clear (or hidden) engineering motivation in modern practice is that some of the "Extra Inquisitive Engineers" although might have loads of questions to ask but short of extra resource to spend/waste on the issue, thus on behalf of the given **RUP** they were obligated to "doing things appeared right in a hurry" rather than "slowing down" the pace into **R&D** type of drilling to the bottom

Still obligated or not as to the many enthusiasts, they were not only keeping pace with what is happening but also into keeping track of what had already happened meanwhile preparing for what is about to happen until whenever it finally settles in their mind – especially on those *timeless* advices. Why? Perhaps it is due to their advancement in fact-finding way of thinking becoming more demanding and more sophisticated in all regards

But quite fortunately that these days for each familiar crane type or popular crane function, there had been an "official $\mathbf{f_T}$ value" assigned accordingly by some of the "matured" Codes and Standards (yet whether that value is reasonable or not would be another matter.) But then in a not so lucky situation:

Be it too high or too low but what if the $\mathbf{f_T}$ value for an unusual Mill function were not expressly covered?

What more could we ask for beyond following the "rule of thumb" in our normal practices? Although we were provided (coached) by the governing Codes or Standards with a specific $\mathbf{f_T}$ factor to go by, but other than being "technically" nosy or observant, has anyone ever wondered why using this particular $\mathbf{f_T}$ value and why not a different number? Or is there any clarification?

Knowingly by a fact, suppose the "what is" part of $\mathbf{f_T}$ had been taken care of as given in so-called Codes and Standards, sort of; but all through the bygone evolution of this **sacred factor**, has it ever, seldom or never been explained the "how come" part in much needed detail – such as being covered through user notes or supplemental counterpart in the Commentary section − backed up by **R&D** tests or statistically blessed "reason why?"

The next question:

Is it that important for the modern-day Practitioners to appreciate or be familiar with what is behind $\mathbf{f_T}$, how or why it transpires, and just for occasions when in need for their own knowledge or for satisfying their curiosity?

Yes, it is important

Then the biggest catch:

What should we do in certain **RUP**, if the $\mathbf{f_T}$ were plain unknown, or given a value *kind of questionable*?

4.16 Lateral Thrust – The Ground Zero

Recalling earlier on the topic:

*Lateral thrust **Px** is induced **mostly** from the trolley's forward-and-backward movements along **X**-axis*; and indeed the term "mostly" could be vindicated herein not just for **argument's sake**:

Px can be triggered by a direct trolley-bumper collision whether through forceful or mild thrusting, but it can also be brought on from overhead crane's framing imperfection in form of reverse coupling from an out-of-squared bridge crane traveling at skew against the norm (its influence to the structure is not of interest here)

While confirming **CRG's** design loads by Normal Structural Engineers' Judgement on **Px** load's behalf, the reasonable place to examine in detail should be the as-rated lifted load capacity **Pc**.

After all, the as-rated **Pc** has to be the most realistic source of service *live load* – which, of course, is additive to the *dead load* − combining (1) all moving equipment and gears mounted over the crane bridge and that of (2) all stationary portion of crane skeleton supporting the moving parts thereof thus establishing an equally important share of **CRG** design basis much as **MWL**

Anyhow, there should only be a handful of exceptional conditions (or loading/unloading stages) that **Pc** could possibly be brought into the action on its own merit since the **interface** between **Pc** and the trolley was entirely *under the control of Crane Operators.*

It is interesting to appreciate or imagine how and in what way that **Pc** can be "played" or "manipulated" during normal operation:

(a) **Pc** is being lifted up from an at rest state

As trolley engages the stationary **Pc** resting on the **XZ** floor surface, it actuates the lifting action with respect to **XZ** plane under these configurations:

- Either straight up at exactly 90-degree angle
- Or at an initial angle **Φ** other than 90 degrees

While being lifted at 90-degree, the load-pick-up action is rather cut and dry − merely clinging to the **Y**-axis − from which **Pc** would only add to the trolley weight becoming total vertical load sum without inducing any **LTL**.

When angle **Φ** is at slant off **Y**-axis, unless **Pc** is under one of the situations:

- Being anchored within a solid confine or
- Being held up by unbreakable vacuum suction

Or else the "load" must be "dragged" along the contacting surface prior to being lifted upward − through stages − (1) the hoisting cable (rope, sling, chain or link) must be tightened/straightened to maintain the slack angle **Φ** (2) then with "load" being dragged along in parallel with **XZ** plane (3) until "load" was firmly lifted up and off into an upright **Φ** = 90 degrees.

The in-between stage:

To counter the "dragging resistance" with **Pc** remained on floor, the trolley must (1) overpower the initial static friction force, (2) go through/against a transitional kinetic friction stage, (3) sense the gradual relief as friction fades away and subsides before lifting the **Pc** off the floor

All that could take up fractions of a second, few seconds or however long to complete the lift-up process − but doesn't really matter how much time spent – it is essential to concur with the said sequence of "actions" that actually took place

More importantly, what must be endured by the "trolley mechanism" the whole time was how does friction force come to pass during the dragging action and how does that subside in the aftermath

While playing along through the scenario, trolley must be "capable" of maintaining and satisfying the **dynamic** (or the equivalent **static**) **equilibrium** thereby pitting against the action with counteraction that must be amenable to all probable loading and/or unloading stages, lifting/tilting angles and trolley up-down positions, etc.

By static equilibrium:

The initial force being "recoiled" into the trolley mechanism would simply be (**μ** * **Pc**) where **μ** is the "applicable" coefficient of friction. And the as-said pseudo-static reactive force could be resolved into **X**- and/or **Z**- components accordingly with magnitudes pending on the space angles at which **Pc** was being dragged at. Naturally so the **X**-component would become the **Total LTL**

In many Mills whereby maintained a vastly dynamic operating environment where most **CRGs** called home, it would be rather **unrealistic** to design the structure for lateral loads based on static friction for a number of reasons:

- It is very short lived
- If the duration of static friction were held much longer then, it would likely infer a frozen state as if preventing the "loads" from leaving the contacting (ground) surface, and
- It is never that easy to maintain a truly steady state of static friction in real life (in the bustling operating facilities instead of confirming it in testing laboratories)

As a result, it is more reasonable to simply consider the **CRG**'s **LTL** as imparted from kinetic friction instead of static friction. A debatable subject as kinetic friction has been in certain applications, but the coefficient of friction for use in structural design has its bearing on many variables such as (1) what materials are in contact (*steel against steel, steel against concrete, etc.)* and (2) the condition of contacting surface (indoor/outdoor ambient *viscosity, dry or greasy, in near vacuum or in open air, etc.)*

And finally the not so favorable news to Practitioners – for lacking advice concluded through field testing – there seemed a never-ending uncertainty based on pure physics by digging into the diverse resources trying to fix on the most current, most realistic and most reliable definition of coefficient of kinetic friction. So buyers (users) beware.

(b) **Pc** is already up above the floor in transit

A few conditions of interest:

- Case 1 - Trolley is not in motion

  If both **Pc** and trolley remained steadily in a static equilibrium along **Y**-axis then both entities would participate 100% into the gravity load sum. But while in transient state if **Pc** could swing about arbitrarily in the general space then appropriately each of the **XYZ** components resolved from the swinging inertia effect could contribute to both traction and **LTL** in addition to tallying up gravity load even if the trolley stays in a parked position or being locked in place

- Case 2 - Trolley is moving at constant speed

  If **Pc** stays in static equilibrium (by itself with no swinging action) but does ride along being "**in phase**" with the trolley movement at "constant speed" then, it would add extra mass to the overall momentum (mass times velocity) becoming part of the integral moving mechanism without inducing **LTL**

- Case 3 - Trolley is accelerating or de-accelerating

  Due to change(s) in velocity (or momentum,) **Pc** would accelerate or de-accelerate accordingly with or against the trolley movement. Whether at same rate or impeded rate is a different subject but anyhow, **Pc** would participate in the increasing or decreasing of total friction force being evaluated at the interface where trolley wheels meet the rail(s) on the crane bridge

(c) When trolley rams into the bumper

Trolley-bumper impact induces force along **X**-direction that matches the trolley rail orientation. A trolley may ram into the bumper by (1) either its own tare weight or (2) carrying itself with **Pc**.

To various components of Crane Assembly and Runway Supporting System (whether the **CRG** by itself or nearby supporting column, etc.) the "effect" or "energy/work-done" arising from bumper impact if not much sooner *dissipated, dampened or absorbed* then "what's leftover" could in turn broadcast throughout − from one component to the next, either as action or reaction, being dynamic or equivalent static in nature, or of other attributes depending on our boundary of interests, and for which on **however the free body diagram is drawn** or studied, etc. − *all from equilibrium standpoint*.

But before turning trolley-bumper impact into practical **LTL** design basis, one would not be able to start the numerical calculation process until after all pertinent parameters such as *instantaneous trolley speed, bumper efficiency in absorbing the kinetic energy, bumper stroke length, etc.* were identified and enumerated.

Although crane operator has total control of how and when trolley moves and stops in moderation, but if hitting the bumper with a full slam for a worst case, the amount of impact (or **LTL**) induced could befit a **debatable** matter of *how much time it takes to bring the full momentum down or to a complete stop*, or in other words the *full time history* in the *change of momentum* along **X**-direction that should become the most wanted statistics, again, for argument's sake.

But once the **LTL** effects attributed to trolley-bumper impact were brought on, no matter evaluating base on an individual load source or from combination of many sources but regardless to the triggered amount, it would become a relative complex affair should we follow the **Load Path** (a sketch may help) deeply through which how may **LTL** be passed on to the individual **CRG**:

- The impact force − or the equivalent static force − initiated from trolley's hitting the bumper (known herein as the **Total LTL**) becomes an externally applied force to the crane bridge girder via multi-element *trolley-bumper-bridge* interface, i.e. the *applied **Total LTL** force has to be absorbed by the crane bridge internally as "axial load"*

- From the absorbed **Total LTL** axial load, an *apportioned* not-yet-determined amount of "component force" is transferred from crane bridge to its end trucks at both ends, subsequently distributed from each end truck onto the respective group of crane wheels under it

- The force being transferred (apportioned) from respective end truck to each individual wheel base turns into a concentrated point load, which acts along **X**-axis as crane wheel comes in contact with the crane rail that runs directly over the top flange of **CRG**

- The contacting surface under the crane rail base is always pressing against the **CRG's** top flange by the simultaneous presence of vertical wheel load $\mathbf{P_y}$ matching the railhead elevation

- Owing to the ever presence of vertical load, initially the rail base could not "slip or slide" freely because there is impedance − frictional resistance − developed at the top flange-rail interface

  If there is no relative movement (or slip) between the rail base and girder top flange then, the "static" friction would be transferred "in full" into girder top flange as **immediate LTL**. After all, the rail would tend to displace sideway yet only to the extend as dictated by what were allowed or were caught up by the restraining rail clips, guides or other form of connection (anchorage) medium

- **LTL** as taken initially by the *girder top flange* would in turn implicate the *girder web* and then the *bottom flange* through direct element connectivity within the cross section, in part the girder would have to resist **LTL** in its full amount through its flexural stiffness against rigid-body translation along **X**-axis

- Meanwhile for **LTL** is applied at geometric offset from the **shear center** thus it also engages the entire girder cross section into rotation, through which the girder contributes its torsional stiffness against global rotation about the **Z**-axis through **shear center**

- Only if the girder were stiff (or not so flexible) enough in absorbing the full share of **LTL** as initially apportioned and could rapidly take on the **CRG's** supporting framing (*through tie-back connections and seat bolts*) into further redistribution of that **LTL**, otherwise there it *would take a while* or be of no immediate chance for structural/building columns or even roof diaphragm to have any immediate influence to the final share of **LTL** a girder should take in

Keep in mind that these are "postulated" sequential dynamic events being dissected into logical stages. Presumably these **LTL** reactive events would "happen" at both ends of the crane bridge; which may have taken place at the same exact instant, or with little time lag but it doesn't matter here. The load path evolving from a dynamic nature into equivalent static state may be simplified reasonably as follows:

- Initially a certain percentage of "lateral load" or the **Total LTL** were dynamically triggered into either end of the crane bridge

- Prior to settling down from a "dynamic state," the transient load would go through all the load transferring stages and complete "the full load path"

- Waiting in queue for the girder stiffness to steadily kick into action then participate in settling (or sharing) the final distribution or redistribution of **Total LTL**

That much was said about the trolley-bumper impact but then visualizing what if the trolley involves **no impact** at its bumper but stay on the crane bridge span under pure "static" setup as follows:

- Situating the trolley-load centroid on the crane bridge measuring at $\mathbf{L_a}$ distance from the **CRG** at left and at $\mathbf{L_b}$ distance from the **CRG** at right

- Considering that the **Total LTL** within crane bridge is divided into two portions:

  $\mathbf{P_a}$ associated with $\mathbf{L_a}$ and $\mathbf{P_b}$ associated with $\mathbf{L_b}$, respectively

  If the load source was to push towards left then $\mathbf{P_a}$ must act (react) in compression, which would shorten the length of longitudinal fibers within $\mathbf{L_a}$ while $\mathbf{P_b}$ must be in tension that would elongate $\mathbf{L_b}$ in the process

- Let (**A E**) be the equivalent or average axial rigidity of crane bridge, after applying axial deformation compatibility and joining with the static equilibrium then we have two valid conditions:

  $P_a L_a / A E = P_b L_b / A E$
  $P_a + P_b = \textbf{Total LTL}$

  After solving equations:

  $P_a = (\textbf{Total LTL}) * L_b / (L_a + L_b)$
  $P_b = (\textbf{Total LTL}) * L_a / (L_a + L_b)$

  In the above derivation:

The distribution of **Total LTL** into respective **CRG** is shown related to the location where "load source" is actuated within the crane bridge span, and surprisingly it correlates (1) neither to the impact factor at the trolley bumper for there is no impact (2) nor to the girder stiffness because the girder is not in the picture yet. Baffled?

The resulting formulation for $\mathbf{P_a}$ and $\mathbf{P_b}$ are analogous to that in the definition of **MWL** in **Example 4.1** and **Example 4.2** for which, by simple algebra, we could confirm that the "$\mathbf{f_{tlp}}$" factor for **MWL** is exactly "$\mathbf{L_b / (L_a + L_b)}$" or "$\mathbf{L_a / (L_a + L_b)}$" appeared hereinabove

All in all, it's an age-old evolution looking back at what already were on the design menu, but it still seemed not quite settled among contentious enthusiasts over (1) the derivation of **Total LTL** and (2) how much of that should be distributed into the supporting girders. Lateral thrust is respected for its complex dynamic nature that any renewed ventures in fixing up an equivalent static **LTL** of reasonable magnitude for generic design use is not without controversy.

It may be difficult to come up with a universal approach pleasing every state of applications, but meeting specific project demand as in some **RUPs** for which the structural evaluation or qualification for lateral thrust is deemed critical then a more reasonable (perhaps costly) tactic in evaluating existing **CRG** (in **RUP**) may entail something if not out of the ordinary as follows:

- Prepare reference base line and setup data reading stations ready for taking measurement of girder/rail's lateral deformation

- Prepare to take reading at nodes of interest perhaps making better senses at the rail top and at the girder bottom flange at as many **Z**-stations along the girder length as being practical

- Take measurement and digitize the recorded data before, during and after applying **lateral** crane loading as if the results were taken after an actual operation for as many crane marching positions as being practical to simulate what measured as if dotting/plotting the recorded data in place of an influence line analysis

- Based on the **XY** coordinates of **principal elastic centroid** and **shear center** of the cross section, one could work out the numerical analysis from digitized reading and derive the girder rigid-body translation, rotation function $\boldsymbol{\theta}$, and its derivatives $\boldsymbol{\theta'}$, $\boldsymbol{\theta''}$ and $\boldsymbol{\theta'''}$ at each data reading station

- Calculate the girder stress based on full-blown flexure/torsion analysis incorporating the effects form $\boldsymbol{\theta}$, $\boldsymbol{\theta'}$, $\boldsymbol{\theta''}$ and $\boldsymbol{\theta'''}$ for all load cases, work **backward** in determining the rated lateral load

After all, this is a much slim-downed account of a very interesting but very costly and extremely tedious process. Going through with such extreme challenge seems like an overkill or a mission impossible, but if taming something uncertain into dependable info that the Plant Engineering or Management could trust over for decision making purposes then it would be well worth the effort (money) spent.