Open Sectioned Crane Runway Girders with Arbitrary Profile Geometry

Chapter 2 – Advanced Introduction (Part 1 of 2)

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"Every now and then" we might be stumbling upon obstacles or disorders while fulfilling our Structural Engineering Obligations. Technical roadblocks affecting advancement of production progress could be of intricate varieties or of other natures depending on many factors. Whether of *usual or unusual* trait, stagnations impacting productivity could come to light during a *major* crisis or that of *minor* scale while breaking through a *marginal* bottleneck.

We can always try labelling whatever issues that led us into a weaker position of any significance in any ways by any means; but of **Crane Runway Girder** importance, a good number of issues can be normalized to either *conceptual* or *numerical* in nature.

> Basically any engineering process could be off pace out of wide range of reasons, explicit or implicit, which in turn might cause a minor delay in progress or incite a major setback affecting the entire project. These issues could turn up from misunderstanding (*conceptual*) at inception or from miscalculation (*numerical*) that could come about at any stage of a project

Miscalculated result can always be corrected by recalculation in general – on paper, at least − so long as it had been caught promptly; but misunderstanding structural behaviors or design concept would have been far more punishing if not fixed up in time.

The worst outcome owing to misunderstanding of structural behaviors or design concept should be those exposed many years after the project had closed out long ago. Therefore the incident phasing or timing span of the so called "*every now and then*" in terms of a specific structure's existence should cover as many periods as thereof "*before and after.*"

2.1 The Usual and the Unusual

The issues that may affect Structural Engineering Undertaking − whether of technical or non-technical in essence − could be (1) those out of *usual* yet widely recognized reasons that kept repeating again and again showing same characteristics ranging from chronic shortage in resources, deficiency in problem-solving know-how to poor choice of tools, etc. or be (2) those of *unusual* causes never encountered before or (3) that simply the spontaneous up-to-the-minute types, etc.; with which how familiar to us would depend on what we do and how experienced/inexperienced we are.

> Undue surprises or disruptions to project progress are not uncommon; which could occur during **qualifying** or **re-qualifying** structures of any configurations of any ranks of any classifications
>
> *Usually* frustration and deadlock draw much closer at us when dealing with structures of *unusual configuration commanding unusual behaviors and unusual structural responses linking with unusual loading events derived from meeting unusual design requirement accommodating unusual functional and/or operational needs, and so on*

Approaching setbacks or deadlocks with a positive attitude by accepting *unusual* challenges with intent of prevailing over all that comes is a good inspiration to draw on in order for **Crane Runway Girder** to have a better life in this context.

> The only negative part being, one might not be fully geared up to take on qualification of structures besieged by so many *unusual* elements; it could turn out to be more demanding to deal with if the structure was already strained under ongoing distress that as if extra add-ons were piled up on top of so many innate obstacles to be overcome in the first place
>
> Often times when locked into a disadvantaged situation from (1) misjudging the extent of inherent difficulties and (2) devoid of thorough understanding of the problems' nature, meanwhile (3) if not well-equipped in taking on the technical complications prescribed in these unusual circumstances, we might take in certain familiar or unfamiliar **strategies**, **rules**, **fixes or shortcuts** close at hand aptly out of usual convenience – that's when trouble starts

So often at weighing up an elected problem-solving strategy (rule, fix or shortcut) prior to solving an unusual problem involving a specific tactic, our follow-up approach and the way things turned out may come down to what attitude we have, how we feel and where we stand:

> In hesitant mode:
>
> > We might be (1) in doubt of our own (outmoded) approach on whether it's suitable for the given task, or (2) unsure of the adopted (traditional) scheme is adequate to accomplish our mission − *ended up going nowhere?*
>
> Or else in overconfident mode − if merely trusting our usual instinct or self-approved ruling:
>
> > In the worst case scenario, we could easily succumb to a false sense of satisfaction on the assumption or misguidance into (1) reflecting that our chosen course of action is the "one of its kind" and must be better than other choices if not being the best, or simply (2) riding on a pretentious pride as if we could always manage to a better outcome than employing other means regardless if the judgements made were good or bad – *still, in the worst case scenario ended up going nowhere*
>
> Or prompted by pseudo-confidence driven from unsophisticated imprudence *for simplicity's sake*,
>
> > We might fall for a handy hardy **shortcut** just for getting over the immediate impediment in a hasty. All appeared fine to start until, only if it didn't work out in the end (*usually uncovered many years later*) or by then we might not be around to witness the thrashing moment of unusual aftermaths − *more often than not the very costly kind, unfortunately*

For simplicity's sake, **engineering shortcuts** confer many advantages, and disadvantages, too.

> In some cases, taking that route seemed rewarding from zipping much faster through a less winding course. Yet the experience bestowing such optimistic result or pleasant feeling could be nothing but a flashy mistaken sensation on the downside
>
> The truth being, some of the usual/unusual shortcuts we took advantages of, of which if taken on **inappropriately** for unusually demanding situations, would likely credit up hefty unpaid tolls − usually unseen upfront. These tolls in real (structure's) life must be paid up (with interest) later on; whatever the amount accrued if not being compensated in time out of our own pockets then, for sure would have to be reimbursed by our successors someday

On one hand from being an unsullied object of convenience, a shortcut in essence could be looked on as equivalence of leftover chunks sieved off (whether carefully, conveniently, or else carelessly or poorly) from the balk of the real deal;

On the other hand from being some form of blanketed ways and means, depending on its applications and what purposes that are for, shortcut could be (1) an ideal timesaver at best or be (2) a convenient excuse for not doing what should have been done, or (3) pseudo-ideal as a complete/flawless process in disguise or (4) for the worst a totally wrong path

In Structural Engineering as some of the must-do steps if left off naïvely in favor of *taking it easy* for certain chores then,

An *unjustified* and/or *unjustifiable* usage of shortcut (such as wrong ***shear center*** *location*) would impart undue side effects (serviceability issues) to the structure sooner or later, or even pass on unforgiving financial penalty (hefty repair cost) in due course

Such concerns or the worse often seemed too farfetched to affect us right away − as if unlikely to take place in our own courtyard − but don't be surprised should that actually come to pass someday, perhaps in time when we were no longer in the picture

While solving Engineering Problems in general, certain procedural steps so *simplified conditionally* or being *omitted fittingly* might still work out quite well *for the moment* for selected applications, but only do so as (if) justified.

And yet that offers no guarantee of universal success. Since for any tedious tactic there is, if the earnest version of which were to be simplified purposely then the options of whether trimming it down cleverly or overly, or accepting everything unchanged as-is, etc. should be determined customarily on how unusual or how unforgiving the obstacles, clutters or bottlenecks was on hand

Obviously, not all the usual rules or fixes (or certain traditional engineering/analytical approaches) were equally dependable or deemed appropriate in all situations. Just consider the reality that some of the well-liked schemes (or engineering approaches) might not work in our favor at all if blindly applied to certain unusual state of affairs. That is based on facts, regardless to the fixes were it taken either at full strength or in small dosages

There are many good reasons to chime in a negative ambiance this early on than the other way around, all because it's still a long way to go. But it should be quite palpable hitherto following the closure of **Chapter One** to a common accord that some of the underperforming rules or fixes (predicaments) in Structural Engineering were buried deep down in what it takes to truly apprehend one of these classic yet ever-so-technically-baffling structures:

Crane Runway Girders (CRG) *especially those having* ***Unsymmetrical Profile Geometry***

2.2 Shall We Aim High?

Expressively in **CRG** regards, it depends.

If letting in the wisdom merely through promoting an awareness of the fact that *something essential were amiss from the usual rules or fixes* then it's nothing but superficial at this point. To set foot into the deep, one must substantiate a specific objective to set and reach − which is much more important than moving forward in a hurry without it

Our ambition could be set with reasonable limits or be boundless as well − depending on how aggressive or reserved we/you are. The bottom issue being: Shall we (1) wait and see or do nothing at all − let someone else take things over or (2) do just a little with modest hesitation, or (3) aim high and face off directly with the **CRG** challenges in front of us?

> Should we have chosen the aim-high approach for as much as we could accomplish hereinafter, then one of the immediate goals of this exploitation is trying our best to uncover those lesser-understood puzzles, pitfalls, rules and fixes and whatnot in connection with:

- *The **Pre-construction/Pre-in-service Engineering** of **Crane Runway Girders** and*
- *The **In Service Engineering-Maintenance** (including **repair**) of **Crane Runway Girders***

We may never get there or even close enough for setting the bar at that height – because the coverage encompass (1) all that might possibly happen and (2) all that had already happened, that in a way connects all things convoluted *before and after*.

> On ***Crane Runway Girders'*** behalf, we all know, what urgently needed is a truly "*near-term solution*" to a "*long-term problem*" and it takes steps; but frankly, if we don't know what the real problem is then whatever ended up with may still be handicapped thus we have to know clearly:

>> Where had we been *before*?
>> Are we prepared to win a trivial contest or a full-scale battle *after* all?
>> Are we *now* anywhere near the arena?

Those seemed back-burner abstract issues; yet, we might be surprised at (not) knowing that the most intricate puzzle to be pieced together is in the tally of our self-conditioned *attitude* and self-scored *aptitude*, which is not even the kind of technical savvies but the assertion of our own truthful admittance on, say:

> *How much do we really know of how much we do (not) know about **Crane Runway Girders?***

2.3 Do We Really Know That Much?

Hitting an exact/convenient spot – following what left off from **Chapter One** − to crack open the wealth of practical **Engineering** rules and fixes, from which to come up with a renewed *modular treatment scheme* suitable for both **Inception Stage** and **Maintenance-repair Phase** of **Crane Runway Girder** would take more than a stroke of luck.

For the moment it makes no difference whether to hurry up jumping right in or playing along under no timing pressure simply for we are not yet at the starting line anyways; and it might work better from digging deep into the root first; how? Conceivably by teasing our own "technical mindset" over any whichever Structural Engineering Subjects as seemed fit.

Starting by self-diagnosing ourselves:

Pick any unique topic (**CRG**–related, perhaps) taken up for our personal interest for example, on that subject, no matter how much or how little experience we already have with beforehand, yet spontaneously − like right at this very instant − aren't we perplexed with a rather strange state of mind?

> The unbiased mental measure of our "*knowing what we had already known*" or "*not knowing how much we don't know*" over a particular subject of interest could be much more mysterious to ourselves than to others (our peers) sometimes

> There is good reason for that; wasn't it true on many occasions when we couldn't even gauge the precise measure of "*exactly what we don't know*" simply from lack of proficiency in that subject?

Aside from the cerebral paradox much as generalized, a similar inquisitive urge of self-doubting could have turned up at various stage(s) in our own Engineering/Design Career numerous times; we all had been there, admit to it or not

On making it more relevant to the state of *not knowing how much we don't know*, simply call to mind from our own fixing experience on **A Certain Crane Runway Girder**, say, the design of which was under our own charge at one point; but since then a long time passing, were we ever (never) wondered:

*Have we (not) left behind or (not) left off any "***inadequacies***" from that particular structure we designed and handed in (for fabrication/construction) long time ago?*

Have we (not) appraised ourselves enough through a critical yet fair-minded assessment on a number of wide-ranging **CRG's** *before-and-after* issues?

Only if so then with an extra sober (or somber) sense at this very moment, try a self-diagnosis more seriously through these four **CRG-specific** questions as follow in series:

- Could there be unusual snags hidden from our bygone perception?
- Was that (not) adequate by current standard of what we have been doing?
- Would that become unusually messy and nasty should any structural inadequacy break loose?
- Should that be fixable then, would the handling of such mess be more cluttering than ever expected?

Take note of the stretched-out term: *Before-**fabrication**-and-after-**construction**:*

To those questions, it's one thing having a candid response straight away whether ready or not, it's another thing to realize no matter how many times these **Same Old CRG-specific** questions were recapped over, now or then, herein or elsewhere, but frankly − there is always that one probability – these critical yet fair-minded self-evaluation sensations might have never flashed by even once in our entire career at all, simply from *lack of proficiency* besides other motives, whether acknowledging this fact or not

Being hesitant or ignorant (mildly or utterly) without admitting to our self-made weighty structural consequence is not uncommon

> Not to be satirical, having such (positive or negative) attitude in **CRG** regard could apply to any one of us, especially to those who had *never sincerely* confronted face to face with a distressed **Crane Runway Girder** in grave manner, neither to those who had *very little knowledge* of what a distressed girder might be suffering from

Similar hesitation or ignorance in point should fit equally for many self-styled **Pseudo-CRG Specialists**, certainly fit for (1) those fumbling in the technology darkness or those turning a blind eye to the technical issue on hand, or (2) those who could care less about the grave ramification, even though these structures were already tagged (in black-and-white Inspection Report) as being in distress or unsafe to carry on further, etc.

Or so, similar mentality fits more to those who were too optimistic, too overconfident or too naïve on a fictitious veracity, by which simply because the *structure-already-in-question* (1) might still be functioning (barely) as if nothing (technically evil) had happened and/or (2) might still be standing tall (luckily) in this day and age, etc.

Embellishment at play as it seemed − maybe not − based on what had been pitched as pointed out above. But as so many self-preached lack-of-trust notions floating around as typified and with that sorts of negative, layback or couldn't-care-less kind of mentality, understatements like that often misled many of us to believe that the *structure-in-question* is not in question, or so not in suffering (enough or at all,) or hasn't yet finished its service life span or isn't (barely) into its full-term, etc.

Take one step backward and try being more technically thoughtful:

Each and every one of those four questions needs to have straight answer(s) − in series, of course. But be clear, those *politically-correct* types of answers would not count for arguments' sake, unless the answers were cut right to the point and justified with solid (numerical) backup as appropriate. Be on that ground, if we were given crafty response hidden carelessly behind artificial motives then it would never strike a chord to make serious connection with our self-assigned aim-high mission through the **Chapters** in this **Series**.

2.4 Twist of Fate – A Nominal Structural Past Tense

Our self-assigned aim-high mission fits the traits as being technical soul-searching and fact-finding exercise among other interests in **CRG**.

> Not every one of us had access to full design document or inspection report with respect to a specific girder from the good old days to prove it all, but we cannot maintain an inert mindset as if all bygones were flawlessly well done. If we were so passive or not proactive enough then what emerges from this mission will be another same old same-old all over again – an outcome to be avoid herein in the first place
>
> It is too soon at this point to worry about how it will end or ever will it end. But the key to a fruitful ending with fruitful results − whether that be truly useful or not good enough or be another same-old or totally renewed, etc., don't know but we'll see − actually falls right back from the place where *everything started long before our time*
>
> It should be a sensible beginning from fact-finding/soul-searching of the past while being critical and yet be fair about the validity of evidences. One could choose to watch on the sideline as audience or be a serious participant nitpicking along the way while toiling/enjoying a painstaking exploratory journey – either way, we shall see if indeed a good choice made herein

To begin at this deliberation stage, one of the primary interests is to drill into the "causes" of how and why could so many **Crane Runway Girders** out there following **long** − definition of **long** varies − periods of service in so many Mills were "found" so ill fated (proven *from being repaired after repairs but not yet replaced*) − for all these years and decades, if not a century already − the worse of all, a lot of these newfangled girders hardly put into production line **not too long ago** and/or even the worst ones barely finished the qualifying round of service were already in trouble.

One wonders:

> How did that happen?
>
> … Is it from normal wear and tear?
>
> Why did that happen?
>
> … Is it from ill-engineering?

To the Maintenance/Operation crews doing their everyday share in the Mills, ramification from those issues were of no surprise and not considered a novelty at all to them because they're the ones who see it up close; but those same issues were unseen/untold to many desk-bound Engineers who were not (involved on purpose) on correlated function, unless they were *fully informed from reliable sources, or had been doubling up the engineering duty as fully-vetted Inspectors doing genuine inspection work on regular basis, or else took hint from the latest Inspection Reports handed out by others would do, too.*

Problem: Most of these issues to some among us especially those narrow-viewed old-timers/experts or non-experts, etc., might just shun it off in their opinion as tall tale or fiction; but no matter what, it is undeniably an age-old "classic concern" for a fact and yet still lingering open-ended as of this date; in a right mind, we should not overlook or kick the can further down.

So pick a typical structure in existence and start for our mindset exploratory purpose:

> At completion of the structure's initial design, more often than not, the Engineers (or Engineering Companies) involved in which tend to be (overly) optimistic that there should be nothing harmful left behind or any loose end left off from their design – appraised as being a flawless masterpiece entitled or not entitled
>
> That is a fair and rational rationale out of normal engineering pride and joy. Perhaps in their right minds: Classic concern on the futuristic ill-fated **Crane Runway Girders** was an exaggerated misery or fabricated agony; but on the other hand, we should agree to a reality that "structural ill-fate" does exist with no cynicism, and what's next then? Here in need is answering these questions again:
>
> - Could there be unusual snags hidden from our bygone perception?
> - Was that (not) adequate by current standard of what we have been doing?
> - Would that become unusually messy and nasty should any structural inadequacy break loose?
> - Should that be fixable then, would the handling of such mess be more cluttering than ever expected?

Consider the blatant implication from responses to these four **CRG-specific** questions:

> If (1) the responsive intent were shunned off or (2) all answers were negative then clearly, we might as well go on with "*Good Old **CRG** Way of Business As Usual*" by the same old (deficient) rules and fixes and/or shortcuts (or no shortcut) and call it good, then off we go as if nothing technically at risk or at fault were ever committed, and thus:
>
>> For better or worse, the **Chapter** at hand and the entire **Chapter Series** on **CRG** should come to a close or better off not to initiate the subject/project at hand altogether
>
> But, provided (1) not all answers were negative, or (2) so as long as there is at least one "Yes" then not a homerun but it's a hit to all of us, even though there might be other sticky issues looming on the horizon over these Yeses – but we shall see; perhaps encouraged by such positive admittance, it should motivate our "**CRG**-aim-high-mindset" to wander further into more sophisticate questioning samples as follows:
>
> - Do we really have any idea of what our (past or present) predicament is, and what is the true nature of that?
>
> - Is "what's bothering us/them" on **CRG** only mental, physical, logical, numerical, procedural, engineering or non-engineering, etc. or the mixture of all that apply and beyond?
>
> - Try to rationalize after seeing one of the (most) alarming issues in the Mill; do we really know why and how can tie-back connection bolts at certain girder top flange/column interface were *mysteriously* missing?
>
> - How can a 3-inch diameter anchor bolt be sheared completely at the foundation?

For all doomed matters − whether of **CRG** or **non-CRG** consequential or so for all our *Engineering Conceptual-Analytical-Design-Detailing* triggered quandaries:

Anyone could have been challenged in one way or another by a familiar/unfamiliar thread on intellectual issue not yet been resolved, or by the posting of familiar/unfamiliar query to ourselves or to others not yet been answered, or implicitly casting serious doubt of the bygone not yet feeling at ease with, etc., haven't we?

Whether we let it in or not, have we (not) experienced such uncomfortable situation for at least once at some point in our Normal Engineering Career?

But no speculating any further, in fact, quandary of many brands, both of technical and non-technical varieties, would always pay visit on their own term whether we see it coming or not

Engineering-flavored dooms and glooms seem to call on us whenever improvised. They might show up in any (unidentifiable) varieties in any (unpredictable) measures connecting all or sporadic time frames (unscheduled) ever before or ever after

Whatever the technical inconvenience or quandary we acquired at first encounter, in particular the **Crane Runway Girder** variety, often it might not be as agreeable to our diehard interests, or as appealing to our inert curiosity, or as resolvable handily by our limited expertise or know-how, and so forth.

However, by standard reaction, the handling of unusual/uncomfortable technical encountering is rather straightforward in several ways that may entail: (1) Either establishing a firm initiative to conquer, or (2) taking on within reach from our technical capability until it ends (or get stuck)

But no matter how diligent or how half-hearted our efforts were put into trouncing those uncomfortable encountering, should the resolution of any of the issues be left open-ended then, it stands a fair chance to develop/redevelop into something with features or scopes at level much further *beyond what were initially registered*

Then in one way or the other, these challenges would usually (if not always) be "handled" or "not fully handled" up to a certain extent depending on the action taken; or rationally, some of that could end up being:

- As unresolved or *entirely left off as is*, or
- As conquered completely, but only if the resolution *stands the test of time*, or
- As if hung halfway or somewhere in between *becoming a* ***technical tribulation***, etc.

Consider the twist of fate involving a certain technical tribulation that we have "methodically settled" in our Structural Engineering Past, or for that matter from any of our non-engineering life experiences as well:

What if some of the adamant issues were (believed) well diagnosed, well understood and were (supposedly) well tended to long ago would come back at us − say after a number of Engineering-Career Generations later − with a much harsher vengeance?

For answers, simply gather from past projects we engaged in, any notable case in point should do:

It doesn't matter if we had certain technical downfall experience whether only once or on a few occasions, or none at all; but in the interim we may take hint from one of those thorny structural issues − not of anybody else's but of our own − which in principle were often at variance with the general faith in what a *Good Structural Engineering Quality* should have been

Could it be an event we were unaware of the actuality in that *our proviso for a certain* ***Crane Runway Girder*** *under our own personal attention had been proven to be deficient (by others) with one of these conditions?*

- *Either of **inadequate strength** to endure the normal wear and tear from flexural effect coupled with the ever-irritable torsion influence*

- *And/or of **inadequate strength** to fend off the normal yet abnormal assault from the ever-elusive metal fatigue*

Nobody is perfect, good excuse; but reputations so tarnished that our structure was found having these deficiencies should be an excellent case in point of such vengeance, shouldn't it?

2.5 Time History of a Crane Runway Girder

Prior to signing off with a seal of approval on a supposedly well qualified **Crane Runway Girder**:

> Think it's enough just from paying the earnest engineering respect to avoiding the "*dismal structural condition of being overstressed*" and interpret that as the one and only Structural Engineering Taboo?
>
> Think again;
>
> Some of us would be surprised at how much there is in what we have yet to open our eyes and minds to **Crane Runway Girder**. And in order to truly broaden the structural qualification aptitude beyond the humble act of avoiding *overstressed* situation − as minimum requirement in present tense but confined within a rather narrow scope of interests – perhaps the most direct route reaching there is through multiple instances for one to have:
>
> - Had at least bettered if not perfected our engineering sixth sense in decoding what could possibly trigger fatigue failures with knowledge beyond modest recognition or agreeing with the fact that metal fatigue does come to light to **Crane Runway Girders** in real life, and/or
> - Had deeply involved in the forensic analysis and fixing up of girders suffering from ranges of structural distress, and/or
> - Had survived many an "all-out on-site" battles through the **re-engineering**, fabrication and construction ordeal involving structural repair/replacement/upgrade of diverse scopes, etc.

Obviously all of these feats were "achieved" in past tense with focus only on the sad old existing structures; and the best (worst) part is, most of the experiences in and out of that were kind of grim, a stark contrast to the pleasant happenstance privileged typically in present tense while dealing with new structures.

> Notice an important point, what counts the most is neither on healthy structures being designed toward structurally fit hitherto nor on those being (haphazardly) repaired up to no further than replace-in-kind, but were on those very sick and dying structures in need of life support, if not exaggerating too much − because many **CRGs** were truly sick and dying, right now

What makes our structure – yes, ours − sick and dying? That is what we wanted to find out.

On matters being **CRG-specific**, how/what to appreciate, evaluate and mobilize our efforts and resources needed in treating any distinctive issue varies broadly depending on many factors. Needless to overstate but at the least, it does give quite a different aftertaste between dealing with the sick/dying old ones and those (supposedly healthier) much newer ones or those not yet in existence.

To get a feel for it on how a **CRG** could became sick is simple;

It doesn't matter if we were short of explicit knowledge in handling **CRG–in–distress** or the like, but in lieu of achieving any of those as-said engineering feats of interest in present/past tense, we could still be taken in and paint the picture by applying our Engineer-Inspector Foresight on finding some of the "probable happenings" to an <u>already aged</u> girder, which happens to have a track record that could go something like this:

The passing of that girder's typical lifespan:

Once upon that day when the engineering duty was officially done, its qualification status could have been well under control and certified by the design rules per good design intent − provided those rules made the best engineering sense back then − from the outset; thus Working Drawings as part of the deliverables obligated under the original contract were "accepted and approved" for shop detailing, fabrication and for construction, and then the systems were placed into service, with confidence

… <u>Many years – series of loading/unloading sequences and cycles later − went by</u> …

Then as provisional as mimicked hereafter:

The projected/anticipated good structural performance purportedly lent from good design should be long-lasting and <u>not</u> falter into a stage full of gloomy crises or into a distressed ending, which when it does is rather contrary to the as-expected original prospect

Yet whatever destined to take place owing to "design slips" will eventually be out in the open and that could be as much as substantiated either (1) as alleged from the most recent Inspection Report(s) or otherwise (2) as manifest already from the latest structural deficiency observation(s)/finding(s) revealing **Nothing Better** than a <u>failed</u> grade

Graciously speaking with deference:

Such consequence from the "provisional cancerous happening" could be dead serious but was somewhat downplayed deliberately hereinbefore so to maintain being respectful to others or be political correct by engineering account. But doing nothing and merely seeing it, saying it or hearing it doesn't really add up to anything helpful in reality

Most of us, Structural Engineers, don't see "structural cancer" on paper or on computer screen unless experienced in looking for that on purpose and staring at it up close on site. And for a fact, some of the grave cancerous situations had already come to pass to so many girders of various ages, sizes and shapes, etc. and so <u>what "we" don't see does not mean it's not there</u>

Why is it so in the revealing? *Something must have been amiss, obviously*. Off the record if so elected, but what is the right thing to do next?

If we were not part of the "responsible" party who had caused or staged the "happenings" then, would it give a good enough reason, be it politically correct or not, to blame on our predecessors, grumble over the bygone to no avails, or instead *should "we all" refrain from encouraging negative vigor but to challenge ourselves into provision of much improved ways and means?*

<u>The reality:</u>

No matter driven by what spirit at what pace, whether in the thick of a slow-motioned information gathering session or keeping up with a fast-paced engineering analysis/design progression, any decree to any specific engineering issue stands a fair chance of being **challenged** through test of time, over and over again. But provided that the **challenges** were primed with good intention into striving for better handles of the circumstance into much more superior ways and means so then all those enunciated challenges should suggest nothing wicked but rather as part of *normal passing of technical evolution*.

Therefore it is quite commonplace in the midst of continual challenges that a certain tactic deemed acceptable once upon a time yet could be proven inadequate or befitted questionable after some years if not many generations later. This should aptly apply right on target to our very subject on how to optimize and better the design of **Crane Runway Girders** fittingly *with **adequate** strength*, as minimum, capable of:

- Enduring the anticipated *loads* and *effects* – bending, shearing, warping, etc. – with orientation bounding all six-degree-of-freedom, and

- Fending off any and all tarnishing from being *overstressed* from events whether of metal fatigue driven or non-fatigue driven

Hitting home isn't it?

2.6 The Attitude of Knowing Nothing

Nonetheless on account of purported technical evolution to this day, combining which with automation so then many good old time-consuming chores can be completed almost instantly − the engineering of **CRG** is a good example − what's left for debate or questioning is the validity of technique used for those chores.

> Reasonably so whether if aided by taking full advantage of the latest and greatest in the public domain or acting on normal reflection through personal experiences, there could be plenty of judgments being opined on the **Structural Engineering Techniques** of **Crane Runway Girder** − from among many Readers (Experienced or not) of various sources of proven know-how − no doubt about that
>
> But let those "opinions" be held off for time being as we've barely warmed up from a few pages into the **Chapter** with long way up ahead still. Therefore instead of taking positions at the topic at a stage this early, what if we were to play along on a new/renewed set of mental agenda, to which, if not yet everyone were on the same page in recognizing (1) how rigorously the technical burden is to be carried straightaway and/or (2) how costly the economic value is at stake in the long run then, wouldn't it be more "delightful" by staying put as if "knowing nothing" before the inning (**Chapter**) in progress comes to an end?

While playing (or learning to play) an honest game (of practicing **Crane Runway Girder Engineering**) by instincts under a primitive state of "knowing nothing," a certain prudent stance such as (1) being more **cautious** and more **conservative** in general, or (2) being more **inquisitive** and more **skeptical** at treatments and fixes to dubious issue, or (3) holding off committing to those old rules seemingly **debatable**, etc., should not hamper the progress and yet might help solidifying our technical self-esteem in **Crane Runway Girder Engineering** and beyond when time is ripe.

The rationale:

> It all depends; not every technical problem could be worked out without being at fault in some way if by the same old ordinary fixing mentality or by the same old usual routines (so deeply *simple-bending* oriented) we were so accustomed to in the past, unless proven otherwise of course
>
> What advocated herein just shy of being too philosophical is, sometimes it's best to start the whole thing from square one and meet up frankly with **Crane Runway Girder's** design and qualification issues with/on a clean slate
>
> More exactly with no prior mental commitment and obligation, one needs to forsake those familiar (or unfamiliar) outdated fixes first, then go along with what works out best such as taking a much

closer glimpse of the issue **from the front** – (*calculation or drawing*) − walking deliberately at much slower paces **behind the scenes** – (*inspection report or survey result*) − or brewing up every new bucket of knowledge from fresh ingredients − (*advanced engineering mechanics*) − or approaching **from inside out** with an attitude of re-appreciating the fundamentals − (*strength of material*) − once more and then move on to "see" what does apply and what not; might that be better off after all? We are going to find out

Here we are being humbled (only if willingly) as if knowing nothing of **Crane Runway Girder**, simply move along lest proven such approach doesn't facilitate in the end, but neither should there be any damage done except for squandering a few whimsical moments as we go. And mainly that was the major prodding behind this **Chapter** in that we are about to dig into the subject much deeper from here at much slower pace than the preceding **introductory session**.

2.7 Structure – Load Relationships

If we were to concentrate a bit longer than a quick glancing over the broadest spectrum (should there be one in existence) then likely what hidden behind the glaring of Structural Engineering Aura should stand for things much more than what being Pure Structural.

The livelihood in the broadened field of Structural Engineering – being *nurtured up or broken up* into various divisions or subdivisions − whether as totally unsullied on its own or diversified into a mixture gathering tidbits from other disciplines, it would always be too tricky if one were to compel such a complex subject matter into only a few text messages trying to depict exclusively the vast interest in the domain of Structural Engineering.

No matter how diversified and how elusive it may seem to many sectors of various backgrounds, yet logically in terms of **Engineering Specifics**, the Entity of Structural Engineering with its treatment activities being *normalized* could always be dispensed into a handful of *distinctive ingredients* much as what could be derived from Normal Project Processing Sequence that most of us were so familiar with:

- The pre-defined functional requirements to be met by the prospective structure
- The applicable loads to be taken by the prospective structure so as to meeting the functional requirements
- The realized structure that should function for as long-lasting as anticipated while enduring all consequences as imparted from the applicable loads

Naturally, a parallel flow of logic/context should construe to the **Structural Engineering** of **Crane Runway Girder** as well; we could appreciate a similar deducing sequence through smaller lenses in comparable scale on its behalf, yet from a much-expanded angle:

On the demand side:

Facility Owners as our Buyers would spec out the order of multi-functional requirements with their Business Interests based on Owners/Clients' position

On the supply side:

We the Vendors (Engineers) were commissioned thus obligated to design of structure(s) capable of supporting all loadings coming from all load sources based on design constraints commanding input conferred from all affected disciplines

Thereby as applicable: A typical suite of loading definition for all practical purposes should have:

- Included all conditions as imposed, as severe, as frequent and as anticipated from the functional demand including all pertinent influences such as immediate load effects, inertia effects and ambient/environmental impacts, and

- Included all probable load responses and geometric deformation and/or dislocation effects from all settings such as rail misalignment, etc.

While in midst of transforming from multi-discipline-function requirements into applicable loads as part of the would-be-committed design criteria for Structural Engineering consumption, we are responsible for settling every diverse sense out of all different individuals of different interests from different fields on different platforms on different grounds, etc. or else it's *incomplete to start and won't work in the end*.

Then the question and the answer:

> Why does it sound so much more complicated than ever all of a sudden?
>
> > *Because on **CRG** behalf our intent is to cover all bases − or else we are cutting corners or taking shortcuts*

> *True engineering design should not be dealing with only the favorite matters selectively or brush off undesirable subjects with alibi by saying that are out of scope. In addition, we should be true to the entire **Crane Runway Girder Population** of (1) all ages under all conditions, not that limited to those unborn new ones, and to (2) all sizes and shapes and not limited to I-shapes*

Then the next batch of questions:

> Why aren't all **CRGs I**-shaped?
> And why are some so oddly shaped?

2.8 The Art of Crane Runway Girders, There Is?

When taking up the role practicing "formal" *Structural Engineering*, we could be solving homework problem or resolving real life issues. Regardless to how complex or simple the procedure that is, and no matter how easy or difficult we felt during the solution process, the conclusion we arrived at must be backed up through numerical means, be the results were right or wrong; it is a natural way of proving the engineering quality to our own satisfaction and our peers', too.

Engineering-design criteria vary with the types of structure's functional requirement. Different tools of the trade may be developed and/or acquired for handling assortment of structures exposing various characteristic behaviors in response to diverse loads or load combination natures, etc., or so to certain extent, different number games were "played" for different category of structures facilitating different functional needs.

Qualification of design for structure such as **CRG** and its components often rely on specific tools readily available to us. While in on our "number playing" game:

> Take a specific tool of choice to "play" with; different individual may adopt <u>different modelling approaches</u>. Aptly so the tool as catered to the <u>matching</u> structural problem as given with <u>matching</u> attributes in play, but it could give readily different numerical results even though playing with <u>matching</u> set of loads (and load combinations) owing to <u>different modelling approaches</u>
>
> From a global perspective as it turns out that, different analytical results out of different tools could and would give different ***impression*** to different individuals;

Thereby from a more mustered viewpoint, different Engineers would have different design ideas or reactions from looking at the same (or similar) set of numbers. That is an indisputable fact however we cut it; but not surprisingly that even our own reaction from "seeing" the same subject could vary and fluctuate at different times, too

Quite commonplace that we might be switching back and forth into different temperamental stages under different settings as far as our Structural Engineering Feeling are concerned. To be more specific:

At different occasions for different causes, we might "**normalize**" our reflection to "normal" objects out of our own impulsive accord quite "abnormally" if not rarely as to seeing multiple versions of "**norms** or **chaos**" − at different settings under different working environments − from simple glance of the same set of numerals or the same cluster of digits that:

- On one extreme from relishing the volumetric amount of output off modern automation, we might be prone to being inundated easily from scanning/examining or digitizing/formatting those monotonous rows, columns, pages or screens of text **I/O** or graphical objects

  Finding ways in or out of raw information if not yet organized in specific sequence per specific sorting hierarchy could be very difficult and easily lose touch with the <u>true</u> data characteristics and their <u>true</u> implication to the structure; hence any slip-ups in moderation of "data arrangement" could bring about mistaken sense as if everything appeared to be so dull or pointless

- On the other extreme especially in the bygone days, we could be stuck with rudimentary hand-held calculators or doing long hand (if not using slide rules) that all information would have to be consumed thoroughly/handled (in slower motion) with extra care thus every number in every manipulation might demand extra attention to details and efforts into double-checking after more double-checking – a main source leading to frustration, loss of interest and undue wasting of time

- Or else our data sensitivity could be somewhere in between depending on who we are, what position and what capacity we were in, what were our **norms**, and the tool(s) of the trade available and how it was utilized or programmed, etc.

Albeit after all is said and done <u>correctly</u>, what surprises us is the final design outcome being transferred to design drawings might end up being the same regardless

So very likely,

With innate limitation in versatility of tools on hand for whichever **norms** we acquired from which that may eventually dictate beyond our <u>Organic Structural Engineering Feelings</u> − so long as tools were correctly chosen and utilized appropriately − the resulting <u>Configuration of the Structural Object</u> came out from using those tools might not make much difference to us even if doing it multiple times over. *The problem to worry is, does it make any difference to others.*

The Configuration as engineered (analyzed, designed and detailed) for the same set of loads and same design approach even though had already come to our own satisfaction, yet may or may not end up with an optimum configuration appeasing each and every one of other disciplines one hundred percent, or as being "faultless" to everyone else every single time

But whatever the "final make" of the design, it could be perceived as if all it matters were encapsulated in the "realistic shape geometry" of the structure realized in the end, which by and large is <u>somewhat prescribed</u> by *"what type of load" at "what magnitude of the load" it supports and at "what rate of the loading frequency" is imposed, etc.*

Finally, the spirit tucked behind the abovementioned scenario is exactly what we are getting at. Already, we take note that a subtle connotation should catch on quite noticeably through our repeatedly making connection from Loads to Structures, and thus one could have summarized in general that:

> *The art is in fitting the shape geometry of the structure for the applied load per anticipated function requirements*

2.9 Beware of Out-of-norm Effects

Since the grandest plan in this mission involves "Loads" off **Shear Center** among other sensible interests, it would make better sense and be more practical to generalize treatment of "**Open Sectioned Crane Runway Girder** (**CRG**) **with Unsymmetrical Section**" into much deeper territory covering not only the "Profile Geometry Aspect" but also the "Loading Aspect" as well.

> The ongoing **Article Series** were meant for open sectioned **CRG** with no axis of symmetry (pretty much those with **arbitrary profile geometry**) subject to Crane Wheel Loads applied specifically from top of the rails over girder top flange only; any other offbeat patterns such as having crane rails or load points other than at top flange are **excluded**
>
> Within the scope as understood, as the word "arbitrary" was deliberately made onto the center stage for all to "see" so that *whenever **Crane Runway Girder** (**CRG**) is mentioned from here and on, it would imply the "arbitrary" feature(s) as delineated unless otherwise noted*

After all and by all, we might have placed ourselves under a state of imposed uncertainty, so: *How could a structure surrounded by the as-said double whammy condition (from both geometry and loads) be treated?*

> Aiming too high – perhaps − but is it a good choice and we shall see. Nevertheless before jumping into any **CRG Specifics**, a much nobler move is to aim kind of low to start so we can widen our entry point in order to have a clear view of what we are heading into
>
> > By our time-honored subscription to "simple bending" in treating most structures hitherto, maintaining stress and strain under respective elastic ranges fits to be a well-recognized standard we rarely stepped beyond
> >
> > Hereinafter no exception for **CRG** so we continue to observe the same and that's not going to change but not all, we must be fully prepared for moving the prescribed design qualification yardstick further than "simple bending" − for the word "arbitrary" now becomes the main trigger of all **engineering data chaos** yet to emerge
>
> Taking on such no-room-for-excuse kind of obligation meanwhile looking forward to those bound-to-happen situations upon us, we need to be aware of what surprises might come out of arbitrarily shaped structure under arbitrary loads, the focus is not only the main **CRG** body as a whole, but also its "many" constituent components thereof, so take it from here:
>
> > *Once a member of generalized profile geometry was put under generalized (crane wheel) loads applied at an **atypical load point**, to great extent "simple bending" has to step aside − but not entirely out of the picture − so to make room for other phenomena to churn up a more hostile ambiance throughout the structure's interior*
>
> *What happened?*
>
> > ***Shear center** would have advanced itself into action in full gear harvesting a number of out-of-norm effects preemptively enhancing the girder's every repositioning along with influence from flexure;*

Then bad things will happen if we don't pay due respect to the wrecking power from such event and act accordingly; or more to the point if (1) the basic load responses were not "analyzed" correctly and if (2) the key components were not "qualified" properly, let alone designing the girder to be fatigue-proof

***From a stress/strain point of view**:*

*Mixing up simultaneously the **z**-longitudinal effect with the **x/y**-in-plane shear-flow responses within the same component's cross section seemed normal to comprehend on all outward appearances, but – only to remember a very important fact – it's no longer normal as the deformed profile does not remain plane*

But to identify from among the gross structural behaviors, trying to distinguish numerically which part came from in-plane flexure and which parts were from out-of-plane torsion would be a different story unless we made the habit of always keep tab of where every single numerical object comes and goes – this is where and when data chaos starts to emerge

*Besides, keeping track of the whereabouts and the spreads of x/y/z stress peaks and valleys within the same component/element – of specific x/y/z coordinates – makes the situation worse unless we adopted database-featured logistics on purpose. (More details to come in later **Chapters**)*

The major messing-up of our minds from mixing up flexure with torsion:

Under "simple bending" reigned initiative, a constituent structural component may be constructed as "stiffened" or "unstiffened" element as built; each of which would normally act as a pure tension element or as compression element subject to either axial compression or flexure compression, again, normally

Once mixing flexure with torsion in an open section, a so-called flange could play into a web's position; likewise, a so-called web could act as if playing a flange's position under different circumstances, or so then is everything a hybrid then?

***From a stress distribution viewpoint**:*

*Comparatively, the rather smooth and static feelings of everything being normal and predictable relished in dealing with non-**CRG** matter can suddenly befall into the opposite as soon as we slip and slide (hopefully not) in and out of the many numerical domains for various purposes − for things in **CRG** were established so unique and much more chancy*

*To a cross section under mixed flexure-torsion influence, naturally a component's instantaneous behavior and its immediate interaction with adjacent component(s) would have been so dynamic that the general state of stress can come to be a big mess − a much bigger mess if that was applied to **CRGs** with unsymmetrical section*

Letting some loads go on reversal sense on top of the already mixed-up (messed up) state, the stress distribution of any constituent component − in full or a fragment of it − can switch from being a tension/compression element (rectangular pattern) to a flexural element (triangular or trapezoidal pattern or more complex pattern) and vice versa, or be in and out of being a mixed element (curvilinear pattern), etc.

*Besides, a component's **effective strength** by normal calculation (per simple bending theory) now becomes questionable because a cross section's plane is no longer be planar thanks to warping effect all owing to loading off **shear center***

*The calculated **effective strength** in certain segment/element might maintain <u>in full</u> or switch off either <u>completely and/or partially</u> in a very dynamic manner depending on:*

- *The active **z**-position of the crane in motion and the instantaneous **x/y/z** load sense (plus or minus) and the <u>variable</u> load magnitude and*
- *Whichever type of stress/strain was more (or less) dominant at the very instant of evaluation, etc.*

The as-said generalization should have impact on the effectiveness of each and every element's strength in resisting certain type of stress from a "local buckling-post buckling" standpoint. Yet the issue of full effectiveness or partial ineffectiveness may or may not be applicable in the same context to each and every component concurrently;

*And we see it's quite complicated, all depending on "is it for shear strength" or "are we talking about longitudinal stress" or "the combination of shear and longitudinal stresses" taking into account (1) the <u>local</u> interconnection detailing feature, (2) fabrication quality, (3) section's or element's geometric aspect ratio and (4) where exactly the <u>global</u> **z**-load point is located, etc.*

***<u>Assessment from a design viewpoint</u>**:*

To all Readers who may shed a light past simple-bending, what is the allowable stress (strength) in all these mess?

Forming the habit of recognizing the subsistence of an out-of-norm effects beyond what comes from "simple bending" is barely seeing the tip of iceberg (the next few **Chapters** would lead us gradually to the bottom of it.)

On one hand although the situation of *being generalized or being arbitrary* does demand extra engineering efforts literally lest we do proceed with extreme caution all the way through,

But, on the other hand, we shouldn't be flip-flopping ourselves on one extreme tying ourselves up, becoming too technically intimidated to move forward, or on other extreme − the wrong extreme − becoming so daring from a thought that we could fetch arbitrarily everything (analytical tools and engineering methodology) we want or accept all offered without questioning for our numerical convenience or evading arbitrarily from all things we don't want

To gear up for what we were going after by the norms, as Practitioners, we need to make up several **Important Engineering Design Habits**, which is only a small take in the so-daring Art of Crane Runway Girders. But to minimize any unnecessary **side effects** incidental from **<u>initial</u> structural analysis, <u>final</u> structural qualification, <u>conclusive</u> connection design and shop detailing** and whatnot, we must make certain that the intents as follow were put into effect in practices:

<u>First of all</u>, unless specially designed for or as noted otherwise, the aspect ratio of all the girder component elements including *flanges, webs and reinforcing attachments* should <u>better</u> be non-slender meeting latest **AISC Chapter B** compact criteria – as of this writing − or <u>otherwise</u> be treated accordingly; this would free us from worrying about local buckling

<u>Secondly</u>, in addition to meeting flexural supporting intent, the **CRG** must be supported **torsionally** at both ends (1) against **X/Y** translations better at or near the section's **extremities** – best to avoid connection to the girder web – and (2) against **Z** rotation about the **shear center** for that the girder tieback connection to the supporting building components and/or crane column(s) must always be effective in *preventing the member from sliding off and rolling off and not being torn off neither*

As for the Art in the provision of supports to **Crane Runway Girders**, in short:

*The structural boundary condition with respect to the **Z**-rotation must be fail-safe through properly designed (qualified) connections. Or technically speaking, these interfacing connections must provide a functional equivalence to either "**torsionally simply supported**" or "**torsionally fixed**" condition*

2.10 What Separates Unsymmetrical Section from Symmetrical Section?

To any typical **Crane Runway Girder:**

> When appreciated from as if a pure geometric ornament's standpoint, no matter how it's been etched and built but by the fuzziness as grossly viewed in a **3-D** space, the reflection is only an integral global object rather stocky and relative long
>
> And yet from observing more closely at component level through engineers' eyes, there revealed in front of us were unlimited number of local attributes there ready to be examined, taken care of and be kept tracked of on behalf of each and every **X/Y/Z** node's *load responses, nodal coordinates with respect to **elastic centroid and/or shear center**, effectiveness against local buckling, local stresses, connection details and allowable fatigue strength, etc.*

Continuing with our typical **Crane Runway Girder:**

> As we would go deep at some point but of limited scope in the interim − unless for dealing with *variable-sectioned girders* (to be covered in **Chapter 7**) − the interest is the topographic details across a representative **X/Y** slice of a uniform-sectioned member, the profile geometry of which in all simplifications is maintained uniformly for all **Z**-coordinates
>
> Starting with **X-** / **Y-** axes pair being an arbitrarily fixed **Cartesian** set established by the Users like us, the designated orientations of the orthogonal set could be so as elected for whatsoever that is most **convenient** for user's engineering-design referencing and information **I/O** purposes − for instance, one may choose to line up with orientation of primary load and/or to line up with major components' placement, etc.

For unsymmetrical sections' best interest in general, there is no absolute right or absolute wrong approach in how to align the constituent components with reference to coordinate axes, however:

> It could become tricky in (1) choosing the global **X/Y/Z** orientations and (2) locating the global origin. The question is; shall we locate the origin at the **elastic centroid** or at the **shear center**?
>
> Obviously the answer is quite intuitive if what given is of *doubly symmetrical section*
>
> Yet what to be dealt with mostly in real life is much more complex than *doubly symmetrical sections*; and certainly in practical **CRG** wisdom so to speak, everything seemed more convoluted since the cross-sectional shape geometry found in many common (or uncommon) **CRG** applications could take after an pseudo **I**-shape, a flipped **L**-shape or other figures of more complex geometric makeup such as those idealized visually into the resemblance of a modified **C**, **T**, **E**, upside downed **U**, **M** or transposed **E**, etc.
>
> Therefore there is neither any communal art nor any luck or advantages in all with respect to the fixing of global coordinate system – *however, it can be demonstrated by Readers (if so willing) that whichever axes or systems were chosen, it would be purely for practical purpose and would not affect the destined engineering-design outcome*

Once again as pointed out earlier:

The art is in fitting the shape geometry of the structure for the applied load per anticipated function requirements

---

Prudently speaking, the demand in **engineering effort** and the **level of complexity** involved in handling structural engineering issue of a stick-like member increases in direct proportion to the "**level of irregularity subsisted in the geometry**" of the cross section − provided no other attribute is more dominant than that − thus profile geometry could become the number one concern.

By simple logic, the mathematical treatment procedures would become progressively much more involved in ascending order on the member's cross sectional shape, from *doubly symmetric, singly symmetric, anti-symmetric to unsymmetrical,* or respectively in substituted terms, from *bisymmetric, mono-symmetric, skew-symmetric to asymmetric*

Knowing the basic difference in perspective, one should have no difficulty discerning broadly any given cross sectional shape's geometry into either the *symmetrical* or the *unsymmetrical* category

But what separates unsymmetrical section from symmetrical section?

On an outward lead-in from all given cross sectional shapes, perhaps it wasn't that eye-catching be that symmetrical or unsymmetrical until one tries to examine, for example, the **elastic principal axis orientation**, etc.

In all cases the blatant specifics in *their general profile geometric appearances, component linkage arrangements, components' as-measured dimensions and their aspect-ratio proportioning, etc.* seemed to be sketchy at best as all information are static; yet the true engineering wealth was hidden in the aftermath after deploying all those dull dimensions and figures into the "suite of cross-sectional properties"

The hard effort is entrenched in various "measures of numerical workout intensity" being put in the mathematical manipulations of all pertinent "innermost geometric bits and pieces" that in turn were actually the main source accountable for all of the disparities among the respective sectional shapes and a multitude of their derivatives from that as well

Once again what also set them apart the most?

The *exceeding efforts* required in the *general numerical treatment* to unsymmetrical sections per Engineering Mechanics Principles just about in every aspect anyone could have imagined

To "see" if that is true for a lasting experience:

One merely needs to pick out a few entities of interest from the "section geometric property suite" such as the *location of* ***plastic center*** *or* ***shear center****, the nodal flexural first moment, gross section warping constant or nodal warping first moment*, etc. then try validating their precise numerical quantity by experiencing the raw math behind (better by laborious longhand means) or otherwise try carrying out the primal steps associated with the tedious computation of internal stresses of any variety

Of all the common configurations and member sizes, the section geometric properties needed for **CRG Engineering** cover almost the full spectrum.

Luckily so for ordinary symmetrical sectioned shapes, most (if not all) of the useful properties can be looked up as tabulated in many Design Guides and Handbooks or worked out with relative ease using readily available formulas, or else derived cold and raw using Basic Engineering Principles if needed to

But there is no such good fortune for (1) a vast number of symmetrical sections built-up into non-standard odd shapes and (2) for almost all the unsymmetrical sections because, even if adaptable, close-formed expressions or generic solutions are not practical and therefore hardly exist in the public domain. The classic universal solution technique employed for practical purposes on unsymmetrical sections' behalf has to engage *numerical integration, aggregate summation and/or iteration process, etc.*

Pick and choose; there is no established requirement or rule of thumb in how one should organize the section properties for normal design development purposes. But for the convenience in a full-blown **CRG** qualification session and for better handle of the data management and/or the design debugging chores associated with that process, it may be more beneficial if the collection of section geometric properties were grouped into two logical categories:

(a) Flexure-related properties (**FRP**) such as moment of inertia, which is centroid-based
(b) Torsion-related properties (**TRP**) such as warping constant, which is shear center-based

By traditional solution schemes, most **TRP** could be worked out in succession following the usual steps:

- Starting from locating the elastic centroid
- Setting up the orientation of elastic principal axes and then
- Defining the shear flow pattern … etc.

Unless the riddles were unraveled directly by using brute-force formulation and matrix algebra or by finite element methods employing special setup of element shape function(s) that incorporates warping behavior, or else **TRP** is usually post-processed (numerically) following the lead-in phase when most of the **FRP** was already known

At any rate yet most importantly:

> *There should be of little dispute if we were to nominate the **Elastic Centroid (EC)** from among the **FRP** and the **Shear Center (SC)** from among the **TRP** as the two most notable nobles among all **CRG** section properties*

Ideally, if not all but pretty much that most of "our" headache symptoms encountered in Engineering Mechanics would have vanished as soon as **EC** and **SC** coincide, which is genetically true only exclusively in those "most privileged" members having doubly symmetrical section, like those common-stock-sized **I**-beams as understood, however:

<u>Unfortunately so for structural members directly supporting crane loads</u>: Although by being so privileged in all geometric aspects, doubly symmetrical **I**-sectioned girders if present as standalone member (*even those connected to thrust plate or lacing truss-work in many older Mills*) are **never practical** for **CRG** application if ever adopted for typical Mill functions for many of the obvious disadvantages

More unfortunately for us Engineers, but on the flip side:

One of the most commendable characteristics of unsymmetrical section has been that the **EC** and **SC** (and the **Plastic Center**) never coincide or overlap, and hardly would **EC** or **SC** ever pass through or line up **concurrently** with any axis of **practical convenience** unless being set up deliberately ahead of the game

Accordingly:

*The agreement or the disparity in geometric references between **EC** and **SC*** should be elected and be respected as the single culprit responsible for what separates the symmetrical sections from unsymmetrical sections

A typical garbage-in-garbage-out situation to watch out for:

While maintaining the numerical integrity <u>for unsymmetrical sections' sake</u>, in cases that somehow absentmindedly on our part, *if the "reference" made to either one of the coordinate sets (whether for **EC** or **SC**) were out of place during any computational steps then whatever the computation is geared for would be down into the drain rendering totally meaningless*

In the end let's assume that all parametric terms or numbers were correctly <u>computed</u>, and then a reality check never fails in that no matter how difficult or how cumbersome any treatment may be for symmetrical sections' sake, it would be nothing but a cakewalk compared to the task of equivalent importance for unsymmetrical sections' sake. Sometimes barely from a careless <u>misuse</u> of *mis-located elastic centroid* or *mis-oriented elastic principal axes* is enough to wreck havoc in the flexure matters' dealing already before even messing with the **shear center** and its associated accessories.

2.11 Nothing Is Perfect After All

Consider the fixing of a single concentrated load within the girder span, the key ingredients of a typical load having profound relevance in **CRG** respect were:

(a) The loading magnitude
(b) The loading orientation
(c) The global **Z** coordinate <u>and</u> the local **XY** position *where the load is "pointing" at*
(d) The location of the local cross section's **Shear Center**

This former list of key items is fairly standard compared to how most other stick-like structural members were loaded except for the surprising yet it shouldn't be so surprised emerging of **Shear Center** out of the shadow of **elastic centroid** and more so of **simple bending**.

Anyhow, among all common types of structural member in regards to how they were loaded, **CRG** should standout as one of the most **eccentric** (or the most **eccentrically loaded** that we should clarify) if not the most unique or the most uncommon; all because it must resist the "**moving**" crane loads that mainly came up from the top of the crane rails, on which in further details:

- The "hit-or-miss" or "here-or-there" type of "back-and-forth" marching movements of crane <u>would</u> have resulted into infinite number of **loading instances**

  Each individual instance was characterized by a group of wheels (in fixed number under the end-truck) at established spacing. To be all-inclusive in application in relevance to Structural Engineers' design consumption, one has to consider the wheel group as a full or split unit that could be landed anywhere either staying entirely within and/or partially beyond the girder span

- It followed from more <u>expanded characteristics</u>

  Depending on the as-designed drive mechanism – in that the fixed load group within each **marching pattern** being "driven" under Crane Operator's active control could have "guided" the wheels either to engage individually, in cluster or all in simultaneously along applicable **X/Y/Z** orientations leading into as many combinations of load components (and load resultants) as applicable

- Some of the **X**-loads and **Z**-loads could switch on and off and act in reversible senses,

  And subsequently all load components (except **Y**-loads) could be applied *in random intensities ranging from minimum along orientation with negative sense into maximum of positive sense, in random frequencies and of random sequences, etc.*

Rendered from these attributes is an unusual loading situation so randomized that it hardly conveys any sensation of being in a perfect or standard state of load application at all.

Yet for so many Engineers so pampered by dealing exclusively with section geometry so duly symmetrical subject to loads being so conventional, thus it is easy to be coerced into thinking so much of everything <u>as-expected</u> to be perfect, whether intentionally or not; but then:

> Some may insist on how some of the structural members (1) should be loaded or (2) should have been loaded or (3) should have been fabricated to meet impractical tolerances, etc. – all are tall orders albeit unrealistic except for imposing their sanctioning convenience or for computational expediency's sake and for standardized conceptual convenience, etc.

Nevertheless here lies one of the biggest **misconceptions** of loading perfection in **CRG** regard:

> "*It would be perfectly **OK** so long as the crane rails were centered about the girder web on behalf of minimizing **Y**-load eccentricities with respect to the girder web*"
>
> <u>Trick question:</u> Should this particular notion be **OK** for all **CRG** applications?
>
> The answer is **not as OK as expected**. All may seem so reasonable and logical yet only good for:
>
> - Steady-state immobile load applications and
> - Symmetrical **I**-shaped members
>
> Certainly it is not good for structures that may **deform laterally** when subjected to load sources that are *(1) offset from the **shear center**, (2) mostly transient, (3) constantly in motion and (4) constantly changing/fluctuating in magnitudes, etc.*
>
> Admittedly, to a **CRG** living (surviving) under day-to-day Mill-styled treatments, the "**OK** supposition" of loads centered about girder web is an engineering fantasy at best
>
> > Thus the **OK** condition could only be (1) as realistic as in <u>theory</u> so insinuated from those idealized examples taught in most classrooms or those homework problems given in most Textbooks for studying purpose or (2) as in actual <u>practice</u> so much simplified lacking justification of reasons why making such assumption − all so adopted as in numerous traditional bygone design instances
>
> In fact, even if prearranged and maintained such a "perfect" rail/web-centering provision, it is of no practical advantage except may be a trickle for those **CRG** of <u>symmetrical</u> **I**-shaped sections subject to very light-duty live load applications;
>
> > Meanwhile it might work out provided that the girders were free from side thrust load under <u>assumed</u> **zero** <u>rail float</u> (fluctuation of lateral rail offset) and so on but one may raise the question, can it be true?
>
> In other words, such an assumed perfection is never ever "perfectly existed" in reality for any members having unsymmetrical section

Once again in all generality but more specific to unsymmetrical sections, Any given condition of "perfect rail alignment" with respect to the girder web whether realized by design assumptions or given as wished for, the resulting benefits (if any) might be more Mechanical oriented in favoring the Cranes being operated on the runway at best rather than for the **CRG** structure itself, and we shall see the reason why from further on:

> The way of life for **Unsymmetrical Sectioned CRG** is actually much more woeful than what merely exposed from the geometric irregularity; simply because any externally applied loads from the top of the rail, no matter whichever directions that may come through, *would always be at skew with the* ***elastic principal axes*** *and be at offset from the* ***shear center, practically***

Or so we could examine the way of life for **Unsymmetrical Sectioned CRG** with a different insight; these loading-offset dimensions or the angular-skew displacements should and would better be approached as "imperfection" – nothing is perfect after all.

Understandably, imperfection could sneak up on every **CRG** from various sources except for this case *the imperfection is due to the inherent* ***loading position eccentricities*** *with respect to the* ***shear center*** regardless to the cross sectional shape geometry.

2.12 Pay Due Respect to the Nontrivial Shear Center

As usual and as always on selected subjects of interest such as imperfect loading state owing to load off **shear center**, there would be (endless) discussions among unsettling sectors out there, each could stand by privileged traditions of practice (time honored or not) with radical difference from the others', for instance:

(a) The most dependable sector: Those who recognize and respect the ramification of load positioning imperfection and do take the effect into account in the analysis

(b) Those who don't know what they don't know or refuse to know better and got by "luckily" without being challenged from doing nothing as if they innocently could

(c) Those who understand what imperfection is but inadvertently (artificially) wish, assume or prefer that the effects from certain variety of "load offsets" are negligible therefore willfully do nothing as if the effect does not exist

(d) Those who recognize its existence but choose to believe (or make believe) that could always be mitigated, ignored purposely or be treated (or mistreated) with no knowledge of doing it properly by their "twisted" technical reasoning − out of personal likings or misunderstandings on the subject − ended up doing nothing or doing it wrongly …

Many optimistic wishful thinkers, other than those in the most dependable sector, could at times insist on making unrealistic assumptions or placing impractical demands through design specification mandate or implication, for instances they wish that:

- Load offset can be avoided if the structural system configuration had been detailed properly and constructed accordingly (genuine wishful thinkers)

- Rail/load eccentricity must be avoided or regulated in all operations per engineering design requirement (without knowing if it is feasible or never practically feasible)

- Or through unconcealed but wanton declaration that these issues don't exist, don't matter, or their influence to the structure or in-service serviceability are negligible, and on and on the unrealistic notions (through Engineering trash talk)

If so accepted by the mainstream by reasoning of these arguments into normal engineering connotation then, a certain circumstance that "**does exist**" and whether the condition is "**duly negligible or not"** are usually of two separate issues.

> By sheer intuitive perception, these two circumstances – **exist** and **negligible** − may appear totally independent to each other. But there is "always" a fair chance in reality that the two issues could be closely connected into one single nontrivial design condition requiring serious-minded engineering attentions
>
> It is quite normal to have a run in with atypical nontrivial design conditions subsisted in any of our project ventures of any variety for any purpose, etc. Yet not knowing how to handle these conditions (properly) is one thing but it would be entirely atypical on our part if we do choose to run off shoddily from facing and dealing with them at all
>
> Of **CRG** engineering-design importance − in our own office as well as in the courtrooms − it always pays to form a "pristine habit" of being more **suspicious** or more **paranoid** about anything atypical and/or to any nontrivial situation "not quite" convincing. Do so especially when conducting forensic analysis in that the whole lot of "**negligible**" could suddenly become **nontrivial**; for instance, sometimes as simple as triggered from asking:
>
> - Why a crack was initiated here?
> - How was the shear stress reversal calculated?
> - How was the effect of rail eccentricity taken care of?
> - Why was the crack in the weld or in the base metal? Any difference?
> - Was it because of too many cycles of live load loading-unloading situation?
> - Or more seriously, any concerns of weld quality or plagues from lousy engineering?

With a more vigilant attitude toward anything "not quite" convincing, it should be more helpful to be more **paranoid** than not. From a legal offense/defense viewpoint: If something does exist but ignored then it stands the chance of raising someone's eyebrows sooner or later. Therefore these situations should be looked on as if not being negligible "technically" until **demonstrated** otherwise − more legitimate through actual numbers as calculated from reliable source.

Here is how a nontrivial situation takes shape onto center stage:

> Forces applied with eccentricity from the "norm" may be taken either as a raw **3-D** spatial resultant or that been resolved into respective **XYZ** (or the principal **X'Y'Z'**) components
>
> But regardless of what load-resultant schematic was applied and what quantity was realized, each individual force vector − if symbolized as **P** − would inevitably contribute to additional bi-axial bending and/or torsion moments due to **P-delta** (or expanded in rotational sense **M-theta**) effect when the force is coupled with the respective "**delta**/**moment arm**" offset from the observed norm
>
> In a generic **3-D** spatial significance, **P** could be any force acting along (or resolved into) the generic **X**, **Y** or **Z** axis as relevant, and correspondingly, **delta** would be the associated "companion eccentricity" duly in parallel with or as projected into a component that is orthogonal to a reference axis of chosen or as applicable with respect to either the **EC** or the **SC**, whichever deemed appropriate

There are numerous ways and means in cutting to the bottom detail of every loading ingredient on any given **CRG** application. While fitting various conventions, somehow as mentioned before, some of the system coordinate set of reference were selected to line up with the key loading vector(s) or certain specific structural element(s) to go along with the broadest scope of interest. No matter what we do, the bottom line is always pay due respect to **shear center** because it dictates everything that has anything to do with torsion.

But no matter what were chosen, the **CRG** would always have to resist all the loading "**effects**" implicated from all **six degrees of freedom** (they are forces **Px**, **Py**, **Pz**, bending moments **Mx**, **My** and torque designated either **Mt** or **Mz**) regardless which **XYZ** system is in effect.

2.13 Imperfection – A Nonlinear Progression?

For those not fully convinced over matters of concern brought forward so far, herein depicted as follow is a fairly elaborated version of nontrivial **P-delta/M-theta** effect that should explain how imperfection was nurtured in reality.

The setup:

First on the *geometry*:

Assuming that the centerline of crane rail − over the top flange − of a symmetrical sectioned girder is **perfectly** aligned with the web centerline as initial condition

Next on the *load*:

At some distance away from (either) support at a selected load point (of specific **Z**-coordinate) the girder is subject to two types of load:

- A vertical load **Py**, which is coplanar with (1) the rail centerline, (2) the web centerline and (3) the **SC**
- A coexisting horizontal thrust **Px** over the rail top acting at the same load point as **Py**'s

Lastly on the *structure's natural response to loads*:

It all starts from taking into account only the *rigid-body sideway translation* of the girder due to lateral load **Px** − it should help along herein with a few sketches − as if there is no rotation about the **shear center** just yet

Beginning with Px:

As soon as girder's top flange, jointly with girder web and the **EC**, as positioned directly "under" the "load point" deflected by a linear amount of sideway translation **δx** along the global lateral direction, so would the **SC** to deflect by the same amount − going along with gross rigid-body movement

After all, the presence of **δx** owing to **Px * ey** should be viewed as an ideal mock-up of "loading position imperfection" with respect to both **EC** and **SC**. For time being, **Py** was perfectly aligned with the system **Y**-axis (a fictitious norm) to begin with. But then when the non-zero amount of **δx** shows up, it works as a trigger to all that is to follow

Following the lead-in, the "most-current" or the "instantaneous" load point for **Py** (over the rail top) must also shift laterally along **X** with respect to the original "norm" by as much as **δx** together with the rail and the **SC** that consequentially, all key entities in the link should remain in the same XY plane with the girder web centerline, supposedly

Keep an eye on what may follow by the above setting;

Only in hypothesis:

Should the "girder ends" were not being held as firmly against lateral movement then, the web center plane at the supports would be dragged along with the lateral movement to **somewhat** pay its tribute with respect to the prescribed lateral **X** displacement **δx** taken place at the load point

However, as the "girder ends" went along with the imposed effect, then came several possible outcomes at the girder ends:

- Either, by sliding laterally in complete conformance with the full amount of **δx** but then the girder could be at risk of being laterally unstable if the sliding doesn't stop

- Or else, It has to be stabilized eventually either (1) to try counteracting the sliding through static friction *naturally* or (2) be stopped by mechanical guides or seat bolts *deliberately*;

  Thus by sliding the "girder ends" along with an initial disposition along **X**, which at a brief moment later would be impeded by *friction* or *mechanical guides*, and would finally settle at some fractional amount of **δx** with respect to the web plane at the load point

  In conclusion, wherever the sliding motion stops at would depend on how much the stabilizing friction or how flexible or how rigid were the guiding devices that could hold it steady into equilibrium

No questions, the end condition of not being held as firmly is only a hypothesis as said − or simply not realistic

But on the other hand, if both ends were held rigidly precluding a "rolling off" and "sliding off" then consequently, the "web plane at the supports" must remain stationary in place thus allowing the "web plane" at **load point** − where **Px/Py** were applied − to deflect laterally by the full **δx** (Sketch, anyone?)

The net "sidesway **δx**" realized instantaneously at the "local load point" could be considered as (not the final but) the *semi-final* value of "**induced imperfection**" with respect to the supports, which would inevitably stimulate an additional torque at the load point by measure of **Py * δx**

As a result, the "local load point" would deflect laterally further over, from which the cross section would suffer additional twisting and warping owing to the *semi-final* "**imperfection**" more than that due to the original **Px** and **Py** thus becoming progressively an advancing **nonlinear** affair that doesn't stop until the final equilibrium is reached. Yes, **nonlinear** affair *keeps* advancing

The foregone scenario was played out on a symmetrical sectioned girder. Should we agree with the outcome from the case in point then we shouldn't be surprised at a fact that the said nonlinear effect could have been more (or less) pronounced for unsymmetrical sectioned **CRG** due to the well-established **EC-SC** offset, would it?

2.14 An In-depth Looking into P and Delta

In certain applications, the effect on structure owing to *load-induced imperfections* might be considered "secondary effect" so long as justified. In other words, once justified or when the omissions of such "secondary effect" were readily rationalized, it might be **OK** to take a "shortcut" such that the so-called "secondary effects" were "ignored" in design of those structure subject to specific load meeting specific support requirements, etc.

Still, the question remains for many *unusual cases* on how had the "might be **OK"** been rationalized or justified. Even though it seemed no one casts doubt on the validity of some of the **OKs** on the premises at specific split second yet, but, we shouldn't be surprised at certain instances that someone might start questioning or wondering, in particular on the **OK** statuses especially that were passed on through time-honored engineering hearsays

Yet bear in mind though in any event in the real **CRG** world, a genuine **OK** status must be (1) proven by qualified calculations or field tests and in the world where **CRG** lives and be (2) backed up by long-term in-service performance evaluation records; or else it is **not OK**

To **CRG** in typical Mill operations, "imperfection" is not secondary but another driver leading to legitimate load-response effect that calls for its own share of load-carrying capability or design margin ample enough to go against all odds much like other forms of primary load/stress do

To ignore or not ignore secondary effects is still unsettled at his point to many diehard naysayers; it follows that the key issues now come down to "how reliable and accurate the evidence through numerical means" we can provide; with aims to find out how seriously can the "nontrivial effects" affect the **CRG's** performance − involving both **P** and **delta**:

Numerical accuracy-wise, **P** − acting along the **Y**-axis − is usually well defined in (most) design specifications; and it shouldn't be a major problem to make up if missing, or to verify as needed

Problem is, settling on the value of **delta**-**X** is never so straightforward but should rather be deliberated in (at least) a couple of ways, either by "engineering calculation" or substantiated by "survey results" instead of being "estimated" from untested wild guesses

Characteristically as a dimensional vector pointing along **x**-axis, any *lateral rail offset, imperfection or rail misalignment, etc.* so as measured must be reviewed and evaluated <u>properly</u> in much more detail than just let it be a pure scalar:

> *If the aforementioned offset that comes and goes as typified in the normal* ***elastic*** *structural behaviors (due to loading-unloading events) then it could always be confirmed by* ***proper*** *"engineering calculation" whereas such dimension if already resulted into* ***permanent*** *rail offset (as a component or projection from any everlasting shift, tilt, twist or warp) then only a* ***proper*** *"surveying" could reel in the realistic measure of misalignment*

The key word: **Proper**

But regardless to whether for being permanent or temporary measure, **Delta-X**, given as properly calculated on paper or as accurately measured in the field, could be <u>generalized</u> as the "*Shortest distance taken between the* ***SC*** *and the line of load or load resultant as applicable*"

<u>Next **imagine** with a regular state of mind free from any preset "numerical prejudice" so for the sake of "checking our sensation" over a group of digitized objects or a collection of numerical figures:</u>

When the domain of certain entities was brought into our focus, each individual "number" in that domain could always be visualized from <u>different</u> appraisal perceptions − based on <u>different</u> evaluation perspectives under <u>different</u> assessment criteria or at <u>different</u> mental phases, etc.

At one point or another, and most likely than not, the perception over the "<u>relative importance</u>" of these subjects (a bunch of numbers) even though all were of identical digital nature – in terms of numerical format− but could somehow relay diverse levels of deception or in some way "false numerical feelings" to different observers

Herein consider the prevalence for honest opinion of a couple of dissimilar situations:

First pick an individual number from within a bustling numerical domain; leave it alone and do nothing with; then let in the aftermath from manipulating a collection of numbers, say through addition, subtraction or multiplication etc.,

How do we, as Engineers, "feel" following the two separate incidences would depend on how stimulating the importance of the subject was revealed or concealed from the "dynamics" hidden behind the selected numerals, to which whether from being manipulated (by adding, subtracting, etc.) or not at all

Sounds too vague to catch on?

To expose the "concealed dynamics" to our specific interests fittingly: For example, taking **P** and **delta** each as individual number, and likewise taking their product **P** * **delta** as being multiplied into another distinct entity, so clearly, here we are looking at three independent numerical effects: **P**, **delta** and **P** * **delta**; but what's the big deal?

Isn't there a subtle significance emerging already?

2.15 What Controls How CRG Is Loaded?

Entity **P**, a numerical measure of many pounds or kips or could sometimes be in the hundreds or thousands of other dimensional units, can very well be calculated or guesstimated, even though not at pinpoint accuracy at times but should only be "off" (if it ever does) by not so much from its true value, normally.

So if the as-given values of **P** (or that as calculated) were "off" − or in other words "in error" − then relatively the measure of that might (should) amount to a relatively low percentage points at the most, again, normally as from the difference between 10 and 9.99 as an example

Looking closely at the "erroneous" effect that be up to whatever levels or degrees of numerical seriousness out of **P** alone with respect to its "true value" as measured (or as calculated,) and should that ever affect the overall design outcome at all then, it would probably be "not too far off" and likely be the same several percentages points off as **P** does at best

After all, wouldn't it be rational to suggest that any impact to our design due to such a small "error" out of **P** (if not absolutely true all the times) is quite likely much less critical than if it were from **delta**? Why?

Delta, when assessed by "*standard numerical sensitivity*" against **P**, relatively, is a much smaller quantity, say, an inch or a fraction of that (definitely not in the hundreds.) But then any inaccuracy of that, even so as meager as half an inch off, could be proven to have much bigger impact to the design − although the extent of one inch or half an inch along **X** axis with respect to the girder length along **Z** for a typical girder of, say 25 ^{ft} (300") long is of no big deal.

However, speaking of **CRG** interest for "**X**-eccentricity being **X"** in comparison to "**Z**-length being **Z"** for both as linear dimension, no one would go after **delta** in meaningless reference with the girder's length **L**. What is truly critical to the behavior of **CRG** is the result of multiplying **delta's** scalar amount with **P** into a discrete coupling that pivots about the **Shear Center**

And therefore in that "coupling" significance, *half an inch off from an inch measurement, for example, is a whapping 50-percent difference.* While holding **P** as constant and as far as the final product of **P** * **delta** is concerned, the participating influence to the design from that effect would also be off by at least 50 percent – Readers should know the reason why − which would be a big design goof or mistake if unattended to carefully and that is not just a small explicable error

In the end, it is a relative simple matter pinching for every inch or half an inch of **delta** but indeed a fairly giant step towards the all-inclusive design goal if the effects from all the loadings (from all six degrees of freedom) were fully accounted for in the **CRG** qualification process.

> Sometimes, errors in any magnitude especially those exceeded pre-specified tolerances were inevitable; and that could occur at any stage during any ranks and classes of numerical treatment. Errors are there whether excusable or inexcusable but only acceptable so as proven; and so long as we realize the level of impact that these errors may bring to the structure; that is, *not only at conclusion of the initial design but also the long term structural performance*
>
> On all counts we should be extra vigilant on the level of impact over what could have on our "engineered outcome" from provision and/or treatment of erroneous information, whether as result *committed by an Engineer, an Inspector or a Surveyor, or even from someone's misreading of information on screen, instrument or on piece of paper/drawing, or by a Detailer's wrong stroke of dimension, or a Fabricator's wrongly sized or located bolt hole, or by a <u>wrong labeling on objects/pieces being fabricated/delivered/installed</u>, ... etc.*

Extent of damaging effect committed to a certain tangible entity attributed to human errors is mostly intangible. It at best can be measured in relative term rather than that being absolute. It may appear comparatively insignificant to certain non-structural-engineering disciplines but often much more critical to the overall **CRG Engineering** if not attended to accordingly. For instance it may be a small engineering slip in estimating **P** from 100 ^{kips} load into 95 ^{kips} but a huge design penalty from a mistake of **delta** of 1" eccentricity if being dwindled into 0.5" or increased to 1.5".

> The morale: *don't just pay so much attention to **P** and care so little about **delta*** (especially as it is measured against **shear center**)

Once again since the magnitude of **P** even if not given correctly right on the dot but in most applications could still − not always − be estimated with great precision by "rational" means, thereby the accuracy of **delta** would seem like "the" sole controlling factor of all participants in the loading game.

Then take a guess for applied **P * Delta** torsion's sake:

> Who has the final say or ultimate control of what **delta** is to be in the end?

Clearly the answer is **Shear center**, and therefore:

> *True to all shapes and sizes of **CRG** in all engineering regards, the overall **P-delta** influence in terms of the design outcome has insurmountable amount of bearing upon how accurate the **Shear Center** is located,* after all

Not to be overlooked that several key points were actually buried under all these blabbing if not obvious to some Readers:

(a) As loading eccentricity has controls over the applied bending moments and the applied torque values, and as matter of fact, nothing is ever perfect as to how **CRG** is loaded with respect to the **elastic centroid** and the **shear center** therefore **P-delta** always exists in all **CRG** applications even for symmetrical sections

(b) **P-delta** against the **shear center**, innate in all **CRG** applications, becomes a general exception – as of this writing− to **AISC Chapter F**'s simple bending stipulation

And so to sum it all up among others, "How is **CRG** Loaded" depends mainly on two key factors:

(a) <u>How **realistic** is the loading magnitude, load point offset dimensions, and more importantly</u>

(b) <u>How **reliable** is the **Shear Center** located with respect to the load point</u>

2.16 The Faux Location of Shear Center

<u>Big mistakes:</u> (1) *Misinterpretation* of the true essence and (2) *underestimation* of the vital influence behind **P** and/or **delta** could be far more wrong from merely miscalculating their values upfront;

> <u>An important fact to always keep in mind:</u> Should any of these two quantities − **P** and **delta** − be inaccurate so would the design result, too
>
> > Understandably for typical **2D** building frame analysis, the **P-delta** is rotating about the global plane frame's out-of-plane **Z** (or **X**) and is calculated in reference to the local column's **elastic centroid**. But instead of the like, here we are; what happens if shifting the reference to rotation about the **CRG** cross-section's **shear center**?
>
> *As a result, we've got torsion;* for **CRG Engineering**, the focus is <u>how much</u>

Torsion due to generalized **P** load (**X** or **Y**) whether (1) owing to several individual **X** or **Y** loading instances or (2) their combined actions or resultant into either singular or multiple **P-delta** events, is never a desolate happenstance. Due to the very unique loading nature, it would "spin" in or out (as if) randomly with the concurrent flexural effects into a multitude of in-phase/out-of-phase type of stress flow (or fluctuation) patterns.

> <u>*So there we have the main reason why **CRG** is at no escape from load effects of all six degrees of freedom in a full-blown application*</u>

It's plain to see, *once again as said many times*, that the location of **Shear Center** (**SC**) is "extremely" vital to the amount of torsion that the **CRG** structure has to withstand.

> Our biggest problem could begin unknowingly from not knowing exactly what we don't know, or from not knowing the right from wrong in **SC's** regard
>
> *Consequently, for <u>**most**</u> of non-standard odd shapes (made from joining multiple elements or sections together) or for <u>**all**</u> unsymmetrical sections in general, unless the **SC** coordinates were confirmed by calculation, it is fairly "unsafe" to entrust any opinions based on unconventional wisdoms lacking credible backup from traceable derivation of close-formed formulas or from detailed proviso through rigorous numerical workout*

One of the most perilous advices existed at large for quite some time is the **faux location of shear center** (**FSC**) on behalf of unsymmetrical-sectioned girders of certain configuration.

> To see how misleading it had been to those unsuspected or inexperienced engineers, hereafter is how an unsuspected **FSC** episode would go:
>
> - First assigning the **FSC** for "<u>**CRG** with thrust plate</u>" to follow along a line passing through the "mid-thickness of girder's top flange" with no further (cautionary) remarks on how that may be related to (1) the width and thickness of girder top flange, (2) the width and thickness of thrust plate and (3) other dimensional attributes of the cross section
> - From that preassigned **FSC**, calculating the acquired torsion based only on the **P-delta** (torsion) as lateral thrust **Px** times the sum of the *crane rail depth plus one half the top flange*
> - Doing so on a universal scale with "no regard" to any dimensional variation in the construct of cross sectional elements, as if the same **FSC** scheme would work for all cross sections of like construct/configuration

- More specifically, the **FSC** arrangement would be valid as if no backup calculation is needed

  So the **FSC** would work out (1) by implying a 0" **SC** offset from the **Py** load pointing along (against) either the rail or girder web centerline, or in other words (2) as if the **FSC** is hovering neither over nor under but somewhere out of utter convenience happened to land on the top flange centroid (mid-thickness or the top of flange) and thus it doesn't matter whether if the torsional moment arm per **Px/Py** points left/upward (or right/downward) toward the (true) **shear center** or not

The advices as misleading as foregone on the **FSC** scheme were actually "recommended" in many published materials and were widely adopted by many unwary Practitioners without any questioning.

Whether being offered as a design tip out of time-saving goodwill or as a hidden shortcut trap in reality, but the truth is that by pinning down the coordinate of **FSC** at "the centroid of top flange" in this last instance barely gets half or not even half of the job done correctly at best − if "luckily" so. Why?

Consider some rarely-hit-but-mostly-missed circumstances:

Imprudently, from applying the **faux SC** scheme so as <u>if it were to certain degree accurate</u> by locating the **SC** in top flange; through which it would have secured only "an elevation of the **SC**" or had merely contrived "a horizontal thread of **SC** pointers," under such establishment all that would only make a reference pertinent to the **Y**-coordinate of **FSC** that matches up only with the centroid (mid-thickness) of the top flange while keeping it "afloat" (undecided) along the **X**-axis

Does that make sense?

Or more as an off-labelled engineering advice,
Or a perfect examples of "*usual shortcut*" as mentioned at beginning of this **Chapter**?

See the quandary yet, or not so sure?

Indeed there is a problem, a very big problem. On behalf of better engineering as to whether pledging our faith in any dubious tips for design consumption, we should always ask important questions with confidence that:

- Where exactly is the true **SC** located with respect to the girder web or the crane rail?
- And precisely what is the true **SC**'s **X**-coordinate (and the **Y**-coordinate, of course?)

When there is no backup calculation proving the case, aren't we going to question the authenticity of the preceding "floating" location of **FSC** for that to remain as fictional or be deemed truly genuine? Actually it could easily be resolved (won) or unresolved (defeated) by exercising a little common sense.

Without involving real computations, herein we are not providing an actual resolution but can easily take apart the **thrust-plated** girder **FSC** puzzle:

Imagine if one keeps **changing** some of the components' configuration of a thrust-plated girder – done most often during design optimization − such as what being exaggerated as follow:

- By increasing or reducing the plate thickness (say from 1" to 2" or vise versa,)
- Or increasing the plate width (say from 12" to 24",)
- Or by decreasing the depth or the thickness of the girder web, etc.,

With all that **messing around** of the section component geometry somewhat arbitrarily, then we could/should raise a few key questions of doubt:

- *How could* the **SC** Y-coordinate(s) be left **unchanged** according to the faux scheme?
- In other words, how so would **SC** always remain at constant elevation?
- What keeps **SC** staying at the centroid of the girder top flange on all occasions?
- How could **SC** stay being in plane at constant or no offset with the girder web?
- *How could* **SC** be immune to all that changing in section geometry for thrust-plated girders?
- Lastly but not the least, how could all the above be possible or proven mathematically?

We knew fairly well what a **dimensional changing-unchanging** game could do to the **principal elastic centroid (EC)** because its coordinates would always “relocate” automatically with respect to any changes in the cross section geometry and that really doesn’t take much to prove.

So how could the “geometric relocation” affect **EC** and not applicable to **SC** at all? Or someone didn’t really do the numbers, correct?

As a matter of fact with rare hits and mostly misses, the true **SC** for thrust-plated **CRG** might not even be near or at the centroid of the top flange at all.

2.17 What Happens If The Shear Center Is Off?

The reality – First in theory:

Many engineering problems/exercises could be worked out through various processes using various means; as much as we tried but in the end, the accuracy of result may hit right on the dot or miss by a notch against the (theoretical) exactness of the solution, and that’s understandable

It is also true that the dependability of analytical result of a structure involving torsion usually lives and dies by the correctness of whereabouts of **Shear center (SC)**

Take the case of solving homework problems, a trace of inaccuracy in **Shear Center’s** coordinates may not seem that big of a deal, or else could be of limited scope if it does, even so, but it might still earn a (passing) grade. Whereas in real life experience, a fraction of an inch off had been proven a fairly big deal for many ill-fated girders especially the odd-shaped unsymmetrical sectioned ones

The reality – Then in fact:

*Based on calculation in numerous instances, the genuine **Y**-coordinate of the **SC** for certain **CRG** assemblages were located in some cases “**way up in the air**” far above the top flange or “**way down off into the web**,” and for the worst part the **X**-location could also be situated “**way off from the girder web or the crane rail**” as well*

Our objective can easily be demonstrated by a *real life example* of a 50^{ft} long girder supporting a 20-ton crane. The girder’s **given** attributes are nothing out of the ordinary as far as the length and the loadings were concerned. But what’s unusual is the **acquired** profile geometry soon as the main girder section was integrated into a composite shape with a few external elements attached

An idealized profile geometry model was sketched as shown on **Figure 2.1**; take in from which the complexity as summarized:

- A built-up **I**-shape – (nodes 101 through 210)
- A thrust plate bolted to the girder top flange – (nodes 210 through 225)

- A kick angle at far end of the thrust plate – (nodes 222 through 226)
- Two built-up seat channels plug-welded to the underside of thrust plate – (nodes series 3+)

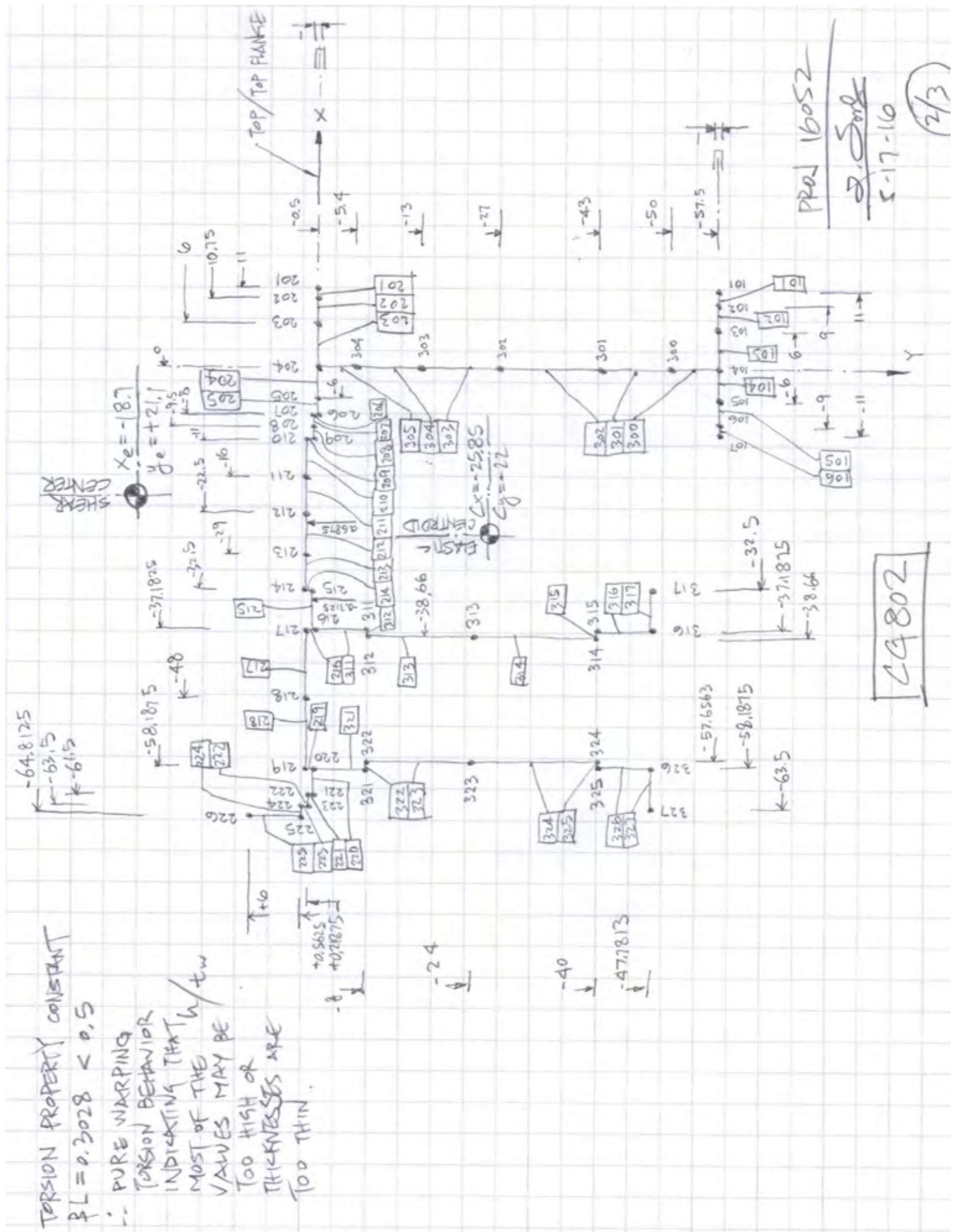

Figure 2.1

What have we basically in overall is a geometric compound resembling a lopsided **M**-shape, which consists multiple "stiffened elements" in that some with links to outstanding "unstiffened leg" near the fringes; and so in existence with no exaggeration, the as-given is one of many horrific examples of what a thrust-plated *unsymmetrical* girder may end up being

Based on the **I/O** results per detailed calculation, as follow listed are the key parameters:

- Girder depth is 58 inches. The full extent of top flange plus thrust plate is 75 inches wide while the girder web is 11 inches measured in from the free tip of top flange

- The calculated **elastic centroid** is 22 inches down from the top flange (which is 26 inches off from the web)

- The calculated **shear center** is nowhere near the top flange but at 21.1 inches above the top flange (and 19 inches off the web)

The **Y**-distance between the **elastic centroid** and **shear center** is 43 inches, and yet the girder depth is only 59 inches. One could only imagine how much the girder may suffer from torsion alone, not accompanied by any other effects yet.

> <u>Could it be worse (or better) in the result if one uses the **faux SC** at mid-thickness of top flange? Would it be worse considering the concurrent effect from lifted weight swinging about laterally?</u>
>
> There might not be a firm answer or if it does then we might need a more thought-provoking illustration; perhaps Readers should take a guess first and see
>
> > By "faux means" *the torsion due to lateral load would be **Px** * (6 + 0.5) for a 6" rail depth plus half of top flange thickness of 1"* whereas based on true **Shear Center** at 21.1" above top flange, the torsion would be ***Px*** * *(21.1 – 6.5)*; see the difference?
>
> <u>See how far off that has been already?</u>
>
> > Turns out the faux torsion of 6.5 * **Px** is about half of 14.6 * **Px**
>
> <u>Imagine, how further off would the reversal/fluctuation of stresses be from warping owing to that amount of torsion?</u>

Let's take upon a hypothesis that the **SC** issue is corrected and well taken care of for now; but besides **SC**, some of the other attributes affecting the girder response to torsion are:

- As-detailed dimensions such as **d,** t_w**, h,** t_f**, L, b**, etc. of all constituent element and
- The aspect ratio of individual element and their pertinent interrelations, etc.

Before proceeding further, heed a timeless advocate on **CRG** treatment for the occasion:

Giving up on **Faux Shear Center Scheme** is an indisputable obligation to carry on; meanwhile only after we have actually "seen" how much "hurt" a **faux shear center scheme** could bring to the structure in some of the Mills or else it is of no other more effective means to convince how important it is to carry out that obligation

In terms of qualitative intelligence, just conjuring up with what does **SC** being way up in the air or way off from the girder web (or for simple case as illustrated in the last example) could bring about:

> As per what already demonstrated thus far, it earns a fair chance that the net design torque value <u>could be</u> **significantly underestimated** if establishing the **SC** randomly or somehow being pinpointed at "the centroid of top flange with zero offset from the rail centerline" although short of a validated numerical backup
>
> In quite a few realistic cases, the torsional moment arm **ey** offset in parallel with the **Y**-axis alone could be way off above the top flange by amount in excess of five or six times the rail depth, or more than that sometimes for some of those **monstrous girders**

The **fluctuation** in overall design torque amount would even be more phenomenal if figuring in the additional **P-delta** effect from **ex** offset − measured along the **X**-direction − *because it is reversible*. But how far off would depend on:

- How unusual the girder section configuration is, and also
- The applied load ratio of **Px** / **Py** as well

Here are a few sample situations on what might cause serious problems; even though it doesn't appear that much problematic to the unfazed many among us:

When looking into the calculation prepared *during the olden days*, it's quite common regardless to what nominal design load ratio of (**Px** / **Py**) might be, the influence on **CRG** design for torsion owing to vertical load **Py** was frequently slipped by many casual designers without that being accounted for − through careless use (untested postulation) of **ex** = 0 or else "saying" that is too small or negligible

And subsequently, even in some cases if **P-delta** from **Py** were taken earnestly in the design, but, if the analytical or design treatment fails to "recognize" that there is a *non-linear* ***P-delta*** *amplifying effect*, which is another design catch if not a glitch – detailed in **Chapter 6** − so then it's still an incomplete (inconclusive) process after all – definitely a not so well acclaimed shortcoming committed not only way back then but also at present time as well

Speaking of **CRG** with symmetrical sections just to make a point,

The importance of $\mathbf{P_y}$**-**$\mathbf{delta_x}$ for design consideration in the old days is sometimes degraded (if not entirely ignored) simply because the eccentricity $\mathbf{delta_x}$ off **shear center** appeared deceivingly insignificant due to the relatively small quantity of **delta-x** (if not at all = 0) contrasting the counterpart **delta-y** *in most cases*;

But the point of argument can be easily confirmed by simple calculation that the true effect from $\mathbf{P_y}$**-**$\mathbf{delta_x}$ can actually rival or exceed the torsional significance owing to the primary lateral load **Px** (see several examples given in **Chapter 6**)

Anyhow, to do it all aptly on all accounts when taking in all probable loading scenarios, the calculation of total torsion on the **CRG** should have reflected not only the simple straight sum of and/or the simple difference between (**Py * ex**) and (**Px * ey**) but should also consider the sign switching affair for fatigue assessment's sake due to the fact that:

- **Px** may be reversible and
- A portion of **ex** may be floating away from the idealized crane rail centerline laterally

Committing error in calculation and being ignorant of the effects from (±**Py * ex)** and **(**±**Px * ey**) were quite common when not familiar with what it takes to truly qualify the design of a **CRG** against metal fatigue. Take that from some of the more immediate side effects:

Carelessness could shortchange (1) the girder ends' tie-back and seat bolt design force, (2) gross bending moment and/or applied torsion, (3) the resulting internal stresses (fatigue- and non-fatigue- essential,) and (4) girder deformations especially the rotational magnitude swept over the rail top, etc.

Therefore if the wrongly calculated value of **Py * ex** alone amounts to five or ten times in excess of (or much less than) what the as-designed-but-wrongly-qualified-as-is values used for the design then, it would spell nothing but trouble in all numerical related matters

Now onto the structural sustainability issue:

Underestimated torsion could implicate major misjudgment on the adequacy of local component detailing arrangement or the global functioning of the overall structural supporting system. Harms that caused directly or indirectly beyond the superficial value from "not knowing what we don't know" are aplenty

Bear in mind that not only the **CRG** members themselves had to absorb what comes their way but also the interfacing effects applicable from the immediate supporting system/components, attachments of structural or mechanical significance, etc. and to take on the assault from metal fatigue somewhat somehow

Extrapolate from what already mentioned, miscalculation affects not only the performance of the girder structure against metal fatigue but also the tie-backs/end connection details at the supporting column – especially the **flexing** of column flange − and/or by chain reactions into the foundation or roof trusses and probably some of the key mechanical and/or electrical components as well

In spite of everything else provided that were done correctly, but there shouldn't be surprises as to why there were so many thrust-plated **CRG** are still having (big) issues. Or so by now after acknowledging the importance of applying properly located **EC** and **SC** in all calculation, it shouldn't be that difficult in deducing the main reason why *cracked base metal, sheared seat bolts and worn crane railhead*, etc. had been the most common structural deficiencies observed in inspections.

Some of those thrust-plated girders of late had suffered chronic structural distress not just once and for all, but many times over, over and over and years after years cycling through numerous in-kind repairs after more in-kind repairs. Guess what?

*The majorities of them were severely under-designed from underestimated **P-delta** to begin with*

And then come times for repair, guess once more?

*Some girders were misdiagnosed again from underestimated **P-delta** thereby subsequently it led to grossly poor engineering fix or bad engineering advisory until meeting their fateful end*

Based on the results from "detailed analysis" of numerous existing **CRG**, the root causes to structural deficiencies for most of these **CRG** were attributed *not so much to the loading magnitudes **P** but almost always the wrongly calculated **delta**, or more so if traced back to the wrongly located **Shear Center** that is. It merely adds more fuel to the fire when complicating the **delta** punishment further with a wrongfully executed Engineering blessing on the girder's fatigue strength*.

We are in no hesitation being much more careful these days. It certainly takes so much more effort to take on even a simple (steel or concrete) beam in engineering design treatment compared to what it took barely several decades ago. Even with all that advancement in technical requirements in place so far, it is still the same old engineering way of life to fall back on Textbooks or Design Guides for detailed matters that don't always get memorized.

Information on **Shear Center (SC,)** warping constant **Cw**, and other important section properties were some of the many must-have references for **CRG** and beyond. As **SC** dictates **everything that has to do with torsion** and **buckling** so it is a good practice to always confirm which cross-sectional shape that some of the formulas being tabulated in the Textbooks or Design Guides were for before tackling **CRG**.

It should be sensible to keep reiterating that any negligence rooted from (1) "wrong location of **SC**" coupled with (2) incidental "loading position imperfection" or any key statistics if unaccounted or miscalculated for could definitely upset the **CRG** design margin in a significant way.

*Readers interested in the classic treatment of this subject may refer to the Authors' ©November 2011 article: "**Warping Constant of Open Sections with Arbitrary Profile Geometry, Rev. 1.**"*

2.18 How Does CRG Behave Under Its Own Dead Load?

Knowing that dead load "is" the simplest load form of all, but why asking the question?

> Simple answer: This has everything to do with the trademark characteristics of unsymmetrical sectioned **CRG**, for which the "**EC** and **SC** never coincide"

First of all, it is a universal occurrence for all structural members of any cross-sectional shapes and sizes, the featured path of dead load resultant:

- *Would always pass through the **EC** of the cross section and*
- *Would always point downward along the gravitational **Y**-axis*

Visibly so for any at-rest upright-positioned members with section profile geometry symmetrical about the web, the dead load resultant would pass through both **EC** and **SC**. However there is a subtle inference from unsymmetrical shapes:

> "The line of load action" due to the "dead load resultant" would never pass through both **EC** and **SC** concurrently, unless the section is purposely placed (rotated) and maintained (fixed) into such a unique non-upright-positioned precarious orientation with proper (but awkward) anchorage
>
> Or else according to the conclusion from "**What Controls How CRG Is Loaded**" a rotational couple (torsional moment) would develop due to a **mini P-delta** effect, where "**P**" naturally is the dead load resultant and "**delta**" is the corresponding load eccentricity, which is the normal (**X**-component/projection of) distance linking **EC** and **SC**

The said torsional moment is continuously applied from end to end, not due to externally applied live load but from girder's own distributed dead weight. Although the influence to the girder design from that effect is indeed **negligible** compared to that from regular **X**- or **Y**-loads, but academically it does exist.

The angular deformation being brought about by the dead load-induced torsion if confirmed by a detailed calculation (perfect as homework problem) is never or barely noticeable numerically or "be seen" with naked eyes on site except perhaps by laser beams. It becomes somewhat pseudo-apparent only for those **CRG** of very long length with very high length-to-depth ratio and/or very low torsional stiffness, hard to tell if it's there but it is there anyhow.

Summarizing from as said only to prove a point:

*Because "**EC** and **SC** never coincide," **CRG** is always under torsion or prone to rotate about its **SC** even under its own dead load.* Furthermore if the member is not properly supported to prevent it from "rolling/sliding off" a slippery surface then it will take place but only theoretically!