OF REALITY, QUALITY AND MURPHY'S LAW STRATEGIES FOR ELIMINATING HUMAN ERROR AND MITIGATING ITS EFFECTS

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Abstract: In this paper, the author reviews the strategies toward to the verification/checking of the construction process for structural safety and performance. The notorious problem with this is that it must be enacted with limited resources in terms of expenditure, time and personnel, while not producing any tangible return. Originally checking and verification were thought to be the essence of quality assurance, through uncovering and correcting faults and errors. The concept of quality assurance has, however been derailed and has become mostly a documentation producing exercise without any real effect on faultiness.

Keywords: Human error, quality control, risk, safety.

Faults and flaws in an industrial product nearly always originate from human error, through lack of attention, communication, competence etc. true to the essence of Murphy's law: If something can go wrong, it will.

The optimization of the checking process for maximum effect in terms of risk reduction and performance must be oriented following such considerations as:

- Error proneness
- Magnitude of risk
- Timing
- Appropriation of resources

Since the checking is organized and carried out by humans, the competence of the people involved becomes an important additional parameter relating to education as well as personal qualifications such as dedication, attention and circumspection.
In the paper, some of these parameters are presented and discussed, mostly based on common sense, in the almost complete absence of scientific data relating to the generation and correction of human error which is at the origin of most or all losses and mishaps.

1. Introduction

It has been pointed out and generally recognized that human shortcomings are the reason and cause for most if not all mishaps in human work. Even acts of God, or what used to be called this name because a human scapegoat could not be found, are beginning to disappear as science appropriates all natural events

4th International Workshop on Reliable Engineering Computing (REC 2010)
Edited by Michael Beer, Rafi L. Muhanna and Robert L. Mullen

ISBN: 978-981-08-5118-7. *Published by* Research Publishing Services.
doi:10.3850/978-981-08-5118-7_011

and quantifies them with return periods, frequencies and probabilities. Even for events that are extreme or difficult to predict such as great earthquakes, hurricanes and tornadoes, engineers are seeking and finding means to control their effects, by providing robustness in the form of second lines of defense, redundancy etc. (Knoll/Vogel 2009).

That leaves only humans and their shortcomings to be blamed for things going wrong. Even where natural events are implied as causes such as wind storms, seismic action, subsidence or flooding, human intervention is found to have been among the factor causing the mishap, by failing to properly account for these effects, or even as the triggering agent, through anthropogenic changes such as global warming, or as recently believed, to have caused an earthquake near Basel, Switzerland, by deep drilling in the attempt to exploit geothermal energy.

More traditionally and directly, the causes of losses through manifest accidents, or due to costs of belated corrections of flaws, are mostly found in structural or physical weaknesses of the constructions themselves which have their origin in errors committed in the building process which were not caught and corrected in time.

It is here that activities such as controls, checking, surveillance, verification, validation, auditing come to bear, whatever the precise name, description or qualifier in each particular case may be, and it is perhaps useful at this point to introduce a distinction between two fundamentally different activities:

- The planned, formalized or institutionalized action.

- The informal filtering which takes place during the building process.

With every intermediate description possible such as the engineer visiting the building site, using his circumspection to apprehend signs of potential trouble (see chapter 9).

This paper shall concentrate on the controlling activities of engineers regarding the wellbeing of the structures, and the parameters which must be considered when these activities are planned and managed. Let us start by putting the process into perspective by discussing the circumstances which are forming the background for what is essentially taking place, i.e. the hunt for errors and their effects.

2. Background

The background of the checking activity is the building process in its entirety, from the first conceptual idea to the physical manifestation, modifications, use and eventually demolition. At any station, and there are many in the network of activities and circumstances which compose the building process, errors can be committed. At the same time, errors and flaws keep being discovered and corrected so that "at the end of the day" the frequency and importance of the residual flaws is such that society, by and large, accepts the result, in the sense that one is not willing to come up with more to pay for added safety and reliability (Knoll 2009). It is normal in the construction industry as it is in most, expectations are considerably higher than what is delivered – everyone is under the illusion that he can get the legendary Rolls Royce for the price of the equally legendary Volkswagen Beetle.

It is this fact of life which represents the first and possibly most important hurdle for the checking activity where it is perceived to be work which is perhaps necessary but rather unwelcome as it hinders the process of construction, costs money and does not produce any perceptible return. Quality or the lack of it, which includes the absence of flaws, is difficult to measure and long in being recognized: The American car industry is only now suffering from a crisis, after several decades of making inferior quality cars.

Budgetary restraints translate into restraint of the checking activity in terms of time spent, in terms of qualification of personnel, or both. The conflict between a speedy and economical construction process and its verification adds to this so that often – and this is not something the participants like to talk about – a number of things go unchecked until they disappear from view such as for example reinforcing steel in a concrete construction, or steel framing disappearing behind ceilings and wall finishes.

The task of organizing and carrying out the checking function becomes therefore an exercise much like what is often said about engineering: To make the right decision on the basis of insufficient information, or in our case: To optimize the effect with insufficient means. As witnessed by the relatively low frequency of serious accidents and major losses, current practice is quite successful producing generally acceptable results. But accidents and costly corrections still happen which could have been avoided if errors had been caught or detected earlier.

The ways and means how this can be done and the rudiments of a methodology to improve it shall now be reviewed.

3. Targeted checking

It is obvious that in order to optimize the effect of the checking activity, in other words to minimize the consequences of errors and mistakes, one has to adopt a strategy which is oriented toward the elimination of those elements of the scenario which are assessed to imply the greatest risks, in descending order until the means run out, in terms of time and human resources.

Among the parameters which are at work here, the following aspects can be noted in a rough list, in the sense of headings for the different groups of ramifications they imply:

- Error proneness
- Magnitude of consequences, risk
- Completeness
- Appropriation of resources
- Timing

– Organization and planning

The complexity of the subject wants it that all of these parameters, or groups of parameters, are not independent from each other but for the discussion, it is perhaps useful to pretend them to be decoupled, at least until major inconsistencies must be ironed out.

4. Error proneness

Three main factors can be identified to be related directly to error proneness. One of them is found to be the stage of the construction process where errors are originating. Secondly, the degree of innovation of the particular scenario is positively correlated to errors committed through ignorance or lack of familiarity. Another major influence is a consequence of the cultural regime in which the work is carried out, including competence of the participants, contractual set-up, mutual trust and collaboration, communication, dedication, circumspection etc.

When reviewing the major incidents this author had contact with in various roles (see Fig. 1 chapter 10), it was found that among the activities making up the construction process, most errors have their origin in the design and planning phases, followed by the construction itself.

This is consistent with the work of R.E. Melchers who found that a terrifying proportion of initial engineering designs are plainly wrong due to calculation errors, faulty hypotheses or important things left out.

The neglected maintenance has only in the last one or two decades begun to manifest itself dramatically in the form of crumbling infrastructures. In many regions of the industrialized world the construction frenzy of the 1950's to 1970's has produced a large quantity of structures which were designed "economically" and built speedily, sometimes with human resources of doubtful qualification. These structures have received little attention over time and in numerous cases, their upkeep and monitoring was consistently put "on the back burner", with the effect that they are now ageing badly, with sometimes hidden weaknesses implying increasing rates of risk, as witnessed by recent accidents. Owners and authorities are becoming alert to the gigantic expenditure this will cause as the correction of it becomes increasingly urgent and costly.

It could be argued that this is no longer in the realm of engineering work in the traditional sense but rather a matter of politics. It is becoming increasingly clear, however that responsibility for these structures and their well being is becoming assigned onto independent engineers which makes the hunt for hidden faults a major task for us.

The errors leading to this state of affairs are of a dual nature. It begins with the apparent economy which was practiced at the time, "squeezing the last drop" out of the – sometimes faulty – design rules of the period, leaving the structures with little or no reserve in terms of robustness. This was followed by a lack of attention, based on the illusion that all work of the past was of good quality and robustness (see chapter 10).

Returning to the first of the factors relating to error proneness it seems clear that it will be a good idea to concentrate a good proportion of the effort onto the product of the design phase, e.g. by independent verification of the drawings before they are issued "for construction". How this is done in detail cannot be discussed here, in most cases the practice has developed protocols which may vary from place to place , following the perceived needs of every scenario, more or less judiciously and strictly.

Other vulnerable phases of the construction process exist obviously and must be attended to, as for example disruption of communication where in the heat of the battle information does not reach its target, or where the checking procedure itself breaks down under the pressure of time – fabrication and placing drawings reaching the checking agent only after the work was executed. Thus, errors may become very expensive to correct, or be left unattended as hidden faults.

Looking at and trying to understand the cultural factor which strongly affects error proneness, leads deeply into the "dark waters" of social interaction and practice of the participants and their environment. Modern contractual relationships tend to be set-up by lawyers, with all the horror scenarios in mind which follow something which has gone wrong. Protective mechanisms are therefore put in place in the attempt to divest each party from as much of the overall responsibility as seems possible, with the logical consequence that pieces of action will be left out where no one consents to be in charge, i.e. responsible. Fear of litigation has become a major factor controlling much of the interaction of the parties, trust and collaboration having been replaced by legal verbiage and personnel devoted to the – perceived to be inevitable – battle for legal and financial advantage. In this author's practice, experience and therefore, opinion, it is evident that the effect of all of this is a thoroughly counterproductive one, with misunderstandings, disturbed communication and adversity leading to omissions, misconceptions, lack of attention and therefore flaws and inferior quality.

Much ink has been spent lamenting the sense of greed in the market economy which has been elected to be the favorite model of economic interaction, construction being no exception. Where short term profit becomes the chief incentive, the tug of war for the perceived pieces of cake becomes the order of the day, at the expense of any other incentives such as the delivery of good work.

Other experiences have demonstrated that were responsibility is made a matter of team work based on mutual trust, errors and their consequences tend to be caught, eliminated or mitigated at much lower expense in terms of money and aggravation. Where every one looks good willed over everyone else's shoulder, instead of erecting elaborate contractual and behavioral barriers, it is easy to see that circumspection comes to bear, rather than being blocked.

Since time immemorial, the lack of equilibrium among the relative power of the participants, with some parties dominating the game, has led to lopsided situations with excessive rebates being imposed, profits being unfairly inflated, and of course, all the elements of what is commonly assembled under the term corruption.

The recent practice of "partnering" where the participating key personalities are assembled in a resort atmosphere, with large amounts of good sounding verbiage being spoken and listened to, do not appear to have borne the expected fruit, i.e. mutual trust. On the contrary, some of that verbiage may have been misunderstood or even ill-intended, leaving the germ of adversity in the process following the initiation ceremony …

It appears therefore to be a good idea to set up the working relationships on an equitable basis and desist from excessive protectionist arrangements. It is an open question whether even a well conceived checking protocol can compensate for what may be named an ill-mannered cultural background, with adversity, fear of litigation and mistrust dominating the scene. Suffice it to say: Watch out !

5. Magnitude of consequences, risk

Risk assessment is one of the major ingredients in every strategy aimed at the elimination of flaws. Since in most cases a complete and detailed surveillance is impossible, the logical consequence is to concentrate on the things which matter, i.e. those features which potentially imply major risks, rather than spend resources on things which are easy to organize but are of little use, amounting mainly to "satisfiction".

It is common practice worldwide to hire testing laboratories where large numbers of concrete as cylinders, prisms or cubes are tested in compression. The substantial expense for this could be applied more sensibly to the verification of more important matters – concrete strength is rarely of primary importance, with the possible exception of high rise building columns where it has become part of a new kind of religion, ostensibly in order to save the last square centimeter of rentable floor area. If there is doubt about the concrete strength, more representative testing methods exist and the crushing of the samples taken off the concrete truck or mixer should be reduced to reasonable measures given the fact that the testing is hardly representative of the concrete in place and takes place too late (e.g. after 28 days) when the typical high rise building has already four added storeys resting on the columns in question. Every engineer has some "skeletons in the cupboard" of his conscience where inferior strength concrete had to be left in place and his task had become to justify this, every other option having been made impossible through pressure from the other participants. A small reduction of the effective safety margin had to be accepted, obviously in consideration of the risk involved which was perceived to be acceptable. This is consistent with the safety margin approach which compensates for modest variations of the real properties compared to what was hypothetically assumed at the planning.

Deviations such as this are "legitimate" in the sense that they are small enough to be consistent with the statistical/probabilistic concept of modern engineering design. Not so for gross errors which may result in deviations of any magnitude and must be eliminated.

When sorting out risks according to magnitude, the description of the potential failure scenario becomes the yardstick which in turn leads to the consideration of structural hierarchy: The wellbeing of an element on a singular or dominant load path is vital whereas an individual load path among many parallel ones commands less importance: All connections in an isostatic truss bridge must be safe lest the entire work is at risk; but one defective wood joist under a floor supported by a number of equivalent elements at close spacing is of lesser prominence. In the first case therefore, attention through design verification, visual inspection and, where necessary, testing must be paid to each and every connection whereas for the floor joists, a more summary type of quality control may suffice.

6. Completeness

No quality control, quality assurance, verification, checking activity can be called good or even sufficient if things have been left out, taking their course unattended. Even where the risk involved may be judged to be modest, a minimum of attention should be given to every element that is eventually given physical expression.

Many construction endeavours are highly complex as can be seen from representations of the building process in the form of networks, bar charts, organigrammes, etc. It is important to remind ourselves of the element of chaos which is inherent in any network process – large consequences can be triggered by even a small variation earlier on – and which is certainly correlated with complexity although no strictly scientific basis for this hypothesis exists to this author's knowledge, human action, including errors, remaining quite intractable mathematically.

In other words, even a seemingly minor initial anomaly may end up leading to consequences of a much greater magnitude. Certain scenarios may lend themselves to commonsensical interpretation, permitting to gage the degree of "chaotic" magnification, as exemplified by the following story:

In a trestle bridge supporting a railroad, some pieces of timber had been classified as having a "soft" core which condition was found in the course of a routine verification, using drilled pilot holes. The meaning of "soft" is a condition which precedes "rot" where strength has disappeared completely, at the "soft" stage some resistance is assumed to still exist. Some years later the bridge was coming up for rehabilitation, a number of pieces being replaced. The rehabilitation work was stopped however before completion for unknown reasons, leaving a portion of the bridge unattended. Again, some time later, a heavy train passed over the bridge bringing it to collapse under the weight of the leading engine. The forensic assessment found that probably, one of the pieces recorded as "soft" had progressed to degrade so that at the moment of the accident the effective safety margin against crushing had become insufficient.

Three things can be concluded from this story:

– Rotting of lumber is something normal and knowledge about its progression is something which can be found in records and, with prudence, applied to this sort of scenario.

– The error committed was therefore one of management where rehabilitation work was not completed, or at least another test carried out.

– In the case at hand, the critical piece was positioned on a singular load path, so that its failure implied the collapse of the entire work. This goes to demonstrate, in addition to the above, that completeness of assessment is of the essence where single load paths are concerned.

7. Appropriation of Resources

From the preceeding discussion three principal criteria have become clear which should guide the attribution of resources where – and this is most often the case – they are insufficient to carry out complete and thorough campaign of check as one would like to do. Among the resources, the following are of primary importance and must be managed judiciously, each of them imposing its limitations onto how much can be done:

– Time

– Access

– Competence and availability of personnel

– Financial resources

It seems obvious that for an effective verification, sufficient time must be allowed so that in the environment of haste and pressure which very often accompanies a construction process, no essential feature escapes attention. Real life does not always favour comfortable conditions however, and most engineers remember situations where they were confronted with large quantities of drawings wanting to be checked in virtually zero time. Very often, errors will be perpetuated in such circumstances because the resource of time was not sufficient. Later stages must be used to make good for this deficit as shall be discussed below.

Access to the elements to be verified is sometimes rather difficult physically, as well as limited in time. Numerous cases exist where the time windows when access was possible, could not be used due to real time circumstances. A notorious case for this are the attachments of most façade and curtain wall elements to building structures. They can be seen only while the cladding elements – which are sometimes quite heavy, being made from stone or precast concrete – are being erected. On most buildings these attachment details will then disappear from view, to remain uninspectable for ever in practical terms. To make them visible again implies a major, very unwelcome and costly intervention either from inside or outside, for each attachment.

The assignment of appropriately competent personnel has always been a critical as well as one of the most difficult elements of the checking effort. The verifying agent must be close to superhuman not to let errors go undetected because of insufficient attention - it is notoriously difficult to concentrate for extended periods of time onto a boring monotonous task, and very often, checking activities are having this character. He must understand the implications of what he sees wherever verification goes beyond the establishment of conformity between one representation and another of the same information.

Consider the stability of a falsework or scaffolding assembly with a multitude of vertical supports, bracings, beams in two or more directions, including imprecise placing, damaged or degraded elements etc. Experience shows that this sort of scenario is among the most notorious ones continuing to cause serious accidents. Falsework assemblies are considered routine work, using proprietary elements which have seen multiple use. Some redundancy may exist in the system but no systematic analysis nor precise representation on drawings is usually provided, nor is there a complete bracing system ensuring lateral stability to all elements as they are stacked one on top of the other. The typical accident involves this fact, with slender beams toppling or buckling laterally, slender posts becoming unstable due to insufficient lateral support, or in a combined configuration of instability, involving several elements.

It is a very difficult task even for an experienced engineer to see and anticipate a stability failure in a large "forest" of posts and bracings – mostly attached with single bolts – and several layers of slender beams with thin webs, some of them worn and torn to various degrees and secured, so to say, by bent nails or screws, some of which may be missing, misplaced or degraded.. The perception in everybody's head is that the same system and elements have seen multiple successful use and therefore everything ought to be as it should, a fallacy which has been involved in a large proportion of accidents.

This being said, it appears quite clear that sufficient time and qualification must be invested to assure the safety of this type of high risk scenario. It is not a good idea to check a falsework assembly while the concrete truck is already waiting with the drum turning. In addition, sufficient time must be allotted for correction, to exchange some elements which are damaged, or to supply the bolt which is missing on one of the braces.

In another case, this author was called to audit an inspection procedure on road bridges owned by a public authority. Concrete and steel structures exposed to temperate climates involving frost/thaw cycles and the use of deicing salts are not aging well and as a matter of strategy, it must be determined where the major risks are being generated when investment toward maintenance is being minimized as it notoriously is. As the one major risk involving life safety the spalling of concrete from the soffit of the bridge decks was identified, with pieces weighing anywhere from a few grams to several kilograms becoming loose, eventually falling onto the traffic below.

The probing for delamination[1] being a cumbersome and costly exercise – traffic must be stopped or diverted, or stages created for access, it is not at all popular with the operational management – resources applied here will be missing elsewhere. However, a number of recent accidents have shown that even a relatively small object hitting the windshield of a vehicle approaching at expressway speed may be fatal. To stop or divert traffic and to provide stages for access involve substantial cost and aggravation, both of which will not be looked upon kindly by the public when it comes to taxes and traffic congestion. Authorities are

[1] The current method is to sound the surface with a hammer – where there is a void due to delamination the sound is "hollow".

not keen therefore to make this sort of investment, in terms of financial and PR resources which illustrates how restraints and limitations are coming to bear.

However, it has never been a good idea to leave something important undone just because it is difficult.

The conclusion from all of this, considering the human resources and time to be assigned to the task, does take the character of an absolute requirement: We need Mr. Superman, the highly qualified and experienced engineer to attend to the task and for whatever time it takes to complete the job. Like all absolutes this leads to absurd consequences which are impossible to follow, Supermen being in short supply and busy elsewhere. It seems a good idea therefore, when his time and attention becomes available, to direct it toward the things that matter, rather than "bogging him down" with administrative chores.

8. Timing

For the optimal timing of checking and verification, a number of aspects should be considered, some of them contradictory.

– Errors caught early are easy to correct without great cost and aggravation. The longer an error is allowed to persist, the more complicated and costly its correction will become.

– Early verification may leave the process vulnerable to errors introduced later which may now go unnoticed.

– Delays and time pressure may cause the different phases of the construc ion process to become asynchronous, i.e. out of sequence, as for example in the case of the detail shop drawings which become available for review only after the work has been executed.

In some cases, this may not be serious as long as the potential error remains visible. In other circumstances, such as reinforcing steel which has been poured into concrete, the scenario has become rather uncomfortable, leaving an uncertainty which is almost impossible to eliminate practically (means exist to detect reinforcement inside a concrete mass but their application is costly and not entirely reliable).

In many circumstances it may therefore be advisable to verify certain features more than once with different protocols and through different personnel. Consider the case of a steel structure. On the drawings it appears quite straightforward, clean and neat, everything fitting together perfectly. Assume the calculations and analysis to be correct and verified. This leaves the fabrication and erection which represent new and different sources of potential errors, caused by mix-ups, tolerance problems, surprises with the erection sequence, all of which will need to be resolved through ad-hoc interventions which may not have been thought through carefully as there was no time to do so in the rush of events, with the crane waiting and workers sitting idle.

The prudent engineer who is being forced to "shoot from the hip" will tend to err "on the safe side". Only, and this must be kept in mind, it is not always entirely clear which side is safe. Reinforcements usually imply additional weight for example which may affect some other parts of the load path.

Failures have occurred due to misuse, overloading or lack of proper maintenance. To be complete, a verification protocol should include monitoring of the structure during its use and, eventually, demolition/deconstruction. This is routinely done for certain classes of structures such as tall towers, or infrastructure owned by the public. Others such as buildings where the structure is mostly hidden from view, tend to escape monitoring, with sometimes tragic consequences.

The use of structures includes very often modification, most of which amount to a weakening/reduction of safety margins. Frequently these modifications are executed by agents without structural insight and escape attention. In this case the review protocol must originate from the owner/user of the structure since normally, no structural engineer is hired to watch continuously and in real time what is being done.

Timing and organization of the verification protocol varies widely with circumstances and must be thoughtfully adapted to the respective requirements of each case, considering all major parameters such as risk, error proneness etc.

9. Organization and Planning

The methodology of the review/checking process includes a widespread menu of interventions, from a rigid protocol with limited and clearly prescribed scope, to a circumspect general supervision, usually accompanying the physical construction, and numerous variants in between.

It is common sense to conclude that at one end of the options where a defined protocol with a limited target is instituted, personnel with equally limited scope of comprehension can be employed, e.g. to establish conformity of one set of representation such as "placing drawings" with the previously elaborated information on "engineering" drawings (the example relates to North American practice, terminology and common practice may vary in other parts of the world, as well as the parties involved in the respective phases of the work). It would be a good idea however, for the engineer who designed the structure, to take a look at the information which appears on the drawings which will be handed over to the construction team, in order to catch potential errors of a more conceptual nature such as erroneous calculations, omissions or other things having escaped attention so far, as they may appear more visible and obvious in the new representation on drawings. For this, a more general and circumspect review is needed, by somebody who will be able to apprehend an error, irrespective of its origin. The draftsman in charge of the engineering drawings may have misunderstood the scribblings and verbal instructions of the engineer, resulting in a mistake which will not be caught through the protocol directed at the mere conformity among two sets of representation.

As will be illustrated in the next chapter, and has been known for the last two decades or so (Melchers et al 1983) errors originating in the design stage are involved in a majority of mishaps.

A key point in the construction process to catch errors can, again as a matter of common sense, be identified when the structure is assembled as completely as possible, just before it is becoming hidden in concrete, behind finishes or non-structural features. The precise time or phase may vary according to the character of the element being considered: A weld becomes hidden when it is being touched up with paint, reinforcing steel when the concrete is being poured, a foundation and its soil base when it is being backfilled. The task to review the work at this stage is usually assigned to a person or team in residence at the construction site, supplemented ideally by periodic visits of the conceptual designer, the senior engineer. It is essential that both agents command a high degree of experience in the world of real construction as they will be asked to recognize the symptoms of something anomalous happening immediately, and to follow up without delay. It is at this point where the most qualified professionals should be in attendance as it is, in many cases, the "last call" for corrective or remedial action to come to bear.

10. A glance at real world events

In this chapter, the author reviews a number of cases where something went wrong and he was involved personally in one role or another. The sample being presented (see table 1) cannot claim to be complete or exhaustive in any way but may be accepted as a snapshot of real life events, in order to illustrate what has been presented in the text above. The cases include two "skeletons out of my own cupboard" which luckily did not result in anything but some additional cost and aggravation. As every engineer knows, the structural engineer is invariably the first in line to be blamed for something gone wrong, and charged with the onus to prove otherwise if at all possible.

The list of some twenty cases with widely varying properties and descriptions suggests that a majority of mishaps have their origin in the design stage. In a number of cases, several stages contributed to the eventual consequences of Murphy's Law.

Table I. Stories from real life

Structural System	Origin of Errors* Correction 0[1)]						
	Design	Fabrication Material Supply	Construction Erection	Use Maintenance	Consequences Loss $	Loss of Life	Problem
Posttensioned Concrete Bridge	*		0		~ 5 M		Local rupture
Tunnel Precast Concrete	*		0		~ 20 M		Insufficient Safety
Façade Precast Concrete				* 0	?	1	Fall
Reinf.Concrete Bridge	*		*	* 0	~ 5 M	5	Collapse
Reinf.Concrete Indoor Parking				* 0	~ 2 M	1	Collapse

Structural System	Origin of Errors* Correction 0[1)]						
	Design	Fabrication Material Supply	Construction Erection	Use Maintenance	Consequences Loss $	Loss of Life	Problem
Reinf.Concrete Slab	*		0		~ 1 M		Collapse
Cable Stayed Bridge	*	*		0	~ 1 M		Rupture
Precast Concrete Box Structure	*			0	~ 5 M		Interior Delamin-ation
Structural Steel Roof	*		*	0	~ 1 M		Collapse
Reinf.Concrete Tower	*			0	~ 4 M		Excessive Cracking
False Work Assembly		*	*	0	~ 2 M		Collapse
Timber Trestle				*0	~ 5 M	2	Collapse
Reinf.Concrete 6 Storey Bldg.	*			0	~ 5 M		Settlement
Reinf.Concrete Balconies			*	0	~N x 1000		Lack of Safety
Struct.Steel Stand Modification		*	0		~ 200,000		Collapse
Glass Curtain Wall		*	0		~ 10 M		Ruptures
Struct.Steel 60 Storey Bldg	*		0		~ 10 M		Lack of Safety
Posttensioned Floor Slabs 33 Storey Bldg			*	0	~ 2 M		Lack of safety
Stadium Roof Polyaramide Fabric	*			0	~ 50 M		Rupture
Stadium Roof Glass Fibre Fabric	*	*		0	~ 50 M		Rupture
Posttensioned Concrete Bridge			*0		~ 100,000		Near Collapse
Industrial Steel Bldg.	*			0			Inconve-nience
Industrial Steel Bldg.			*0		~ 1 M		Lack of Safety
Glass Curtain Wall		*		0	~ 5 M		Ruptures
Reinf.Concrete Slab 20 Storey Bldg	*		* 0		~ 400,000		Excessive Deflection
Reinf.Concrete Parking Slab	*			* 0	~ 6		Collapse

Structural System	Origin of Errors* Correction 0[1]						
	Design	Fabrication Material Supply	Construction Erection	Use Maintenance	Consequences Loss $	Loss of Life	Problem
Hydro Towers Struct. Steel	*	*		0	~ 7500 M		Progressive Collapse
Cable Stayed Passerelle	*		* 0		~ 1 M		Lack of Safety
80 Storey Bldg Marble Curtain Wall		*		0	~ 80 M		Lack of Safety
TOTAL	17*	8*	9*	5*			
1) Correction follows an accident or manifest loss of function.							

Lack of proper monitoring and maintenance was involved in a number of manifest mishaps. This does not reflect the widespread reality of our epoch, with its crumbling infrastructure which, having been built in a frenzy of construction at a time of precipitous economic development, sometimes with actors of questionable competence. Much of this mass of construction (bridges, autoroutes, walls, underground installations etc) was subsequently left to itself without much attention, let alone active maintenance, with the result that the cost of fixing it is now approaching astronomical proportions. This involves a human error of a different scope. It is anchored in our legal political and social culture which produces a tendency to favor short term goals over long terms endeavours. One may perhaps observe some variation of degree of this, correlated to the continuity of government and administration in different social and political systems. Where governments and top echelons of administrations change frequently as is the case in numerous modern democracies governed by alternating party controlled political teams, it seems obvious that the decision makers would tend to take little interest in long term needs: "A few months or years from now it will be somebody else's problem". Murphy's law will therefore take effect more dramatically as can be witnessed for example by the size and frequency of potholes in the roadways, or the general degree of deterioration.

Governments and administrations have recently shown general signs of waking up to this fact of life and paying lip service to the needs of the day, with little manifestation of their good intentions being perceptible yet – budget constraints and political expediency of the moment being what they are.

The author hopes to expand the small sample of sagas cited above to include a greater number of cases as well as a richer review of specific features, with the help of insura ce companies. They possess an almost complete repository of forensic data on the circumstances of mishaps which almost invariably result in massive additional cost, to be absorbed and sorted out mainly by the insurance industry while the actors involved directly are in no position to come up with the financial resources to make good for the mishap, except through the premiums paid periodically.

The sample in Table I is grouped very roughly according to the phase in the construction process where the decisive error was committed and eventually corrected, sometimes reflecting the cumulative effect of several mistakes. In addition, a rough idea is given of the scenario and the consequences such as loss of life, and an order of magnitude of the loss/cost of correction. There are numerous further aspects which should be studied in order to learn something towards improved strategies for "error hunting". Things like contractual relationships, education of the participants, social and political systems, incentives of the parties involved, degrees of time pressure etc, are all part of the picture. It is hoped that information on these "parameters" can be extracted from the forensic and necessarily anecdotal data on real cases.

11. Conclusion

From the reflections made in this paper, it becomes clear that in the pursuit of quality in building in the sense of an absence of serious flaws, a targeted strategy for the apprehension and correction of human errors is of the essence. As well, present day practice leaves much to be desired and therefore to be improved as it is mostly based on the personal and subjective perception of the decision makers about which way is best to go about it, in the absence of any systematic guidance.

At the same time, it seems promising to rationalize the process of review, verification and checking in terms of the various "gross" parameters which accompany the process and govern the potential outcome, such as magnitude of risk, error proneness, limitations in terms of time, financial resources and qualification of the participants etc, in order to optimize the efficiency. Efficiency in this context means to minimize the frequency and scope of loss at the end of the day, in other words to minimize the effect of Murphy's law.

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