Insurance Advisory Tips for Members

Managing Insurance Risk for Topographic Earthwork Survey Assignments

Part 2 - The Engineer's Use of the Original Ground Survey

By Douglas S. McGill

Mr. Douglas McGill is currently self employed (McGill Development Services Limited) and takes a special interest in earthworks science. His firm offers development management services, contract dispute resolution and approval process expertise to a variety of clients in the Greater Toronto Area. This is the second of a series of three articles to outline how the civil engineering earthworks process works and how survey data we collect fits into that process. This article looks at how the engineer relies on the original ground survey to complete earthworks balancing calculations and sources of errors that can lead to claims. Overall, earthworks related assignments are an area of work fraught with service issues and insurance claims so having a basic understanding of sources/causes of errors from all parties involved in the process can help you to manage your liability and reputation.

The first article of this series dealt with managing topographic assignments collected for land development use and this one is going to delve into what exactly the engineer does with that data to establish a site design and an earthworks (EW) strategy. It will also touch on some factors that can alter the engineer's predicted outcome. While the thought that this is not your part of the business may enter your mind at this point, I would suggest that being versed in some of these basics of EW may help you to understand when your data is being applied inappropriately and to allow you to better understand your situation when an EW problem does occur and the accusations start to fly.

Let's start with a few general thoughts on earthworks calculations. I often hear statements from various parties in the industry that earthworks is not a science and that it is not possible to use the many inputs to achieve highly reliable results. I have a one word answer for that – nonsense! I personally have experienced no supernatural events that have led to EW problems. In most cases problems are traceable to errors of actions, communication, incorrect data of one sort or another and erroneous assumptions. Eliminate these and it becomes a science with manageable error margins. Through a diligent study of these problems in my early years at Cosburn Patterson Mather Ltd. (and a few knotty issues to provide continued motivation), I with the assistance of some equally enthusiastic colleagues developed strategies for doing EW assignments that were typically completed within 2 % of quantity predictions (error is defined as imbalance quantity divided by total cut plus total topsoil volume). While certainly there are cases where the margins become larger due to unforeseen issues such as additional road granular, in the normal course of events reliable results are achievable or the deviations explainable. I should also add here that my descriptions of the processes herein are for what should typically be applied to larger scale GTA land development projects. Smaller developments that mix servicing and EW activity without appropriate adjustments to as-built survey practices and records will result in a "dog's breakfast" of accusations when the imbalance of EW or dispute of payment quantities appears.

The Earthworks Calculation:

The EW calculation is an iterative balancing exercise completed by the engineer that seeks to create a "design surface" (which is the elevations defined for all the surface features in a site and what you see when you drive through a built out subdivision) such that when it is compared to the existing ground surface (adjusted for the topsoil stripping depth) that the cut material available on the site is sufficient when combined with all imported materials (i.e. granular brought to site for the road base and reused topsoil) to bring the site to the design grade. This is termed a "balanced site" as it requires neither import of fill nor export of surplus to complete the grading design surface. As noted in the previous article, dealing with an unbalanced site is often costly. For a site that is deficient in material, a source of fill material must be located and the material trucked to the site, dumped, spread and compacted. Availability and distance are big factors in this cost. Conversely, with a surplus, a disposal site must be located and the operation runs in reverse. Balances are of course not always achievable due to limitations of design and existing grade conditions but in such cases the imbalance will be anticipated and a budgeted quantity (cost) will be identified to deal with it. Woe to those who do not achieve it.

This relationship of surfaces is represented schematically in Figure 1:

Figure 1 presents a single cell (3m x 3m) of a grid surface calculation (i.e. the DTM is broken up into hundreds of individual cells that together compose the entire site). The program establishes an OG (original ground) DTM elevation value (from the surface provided by the surveyor) and adjusts this surface for topsoil stripping (typically lowered by 0.3m).

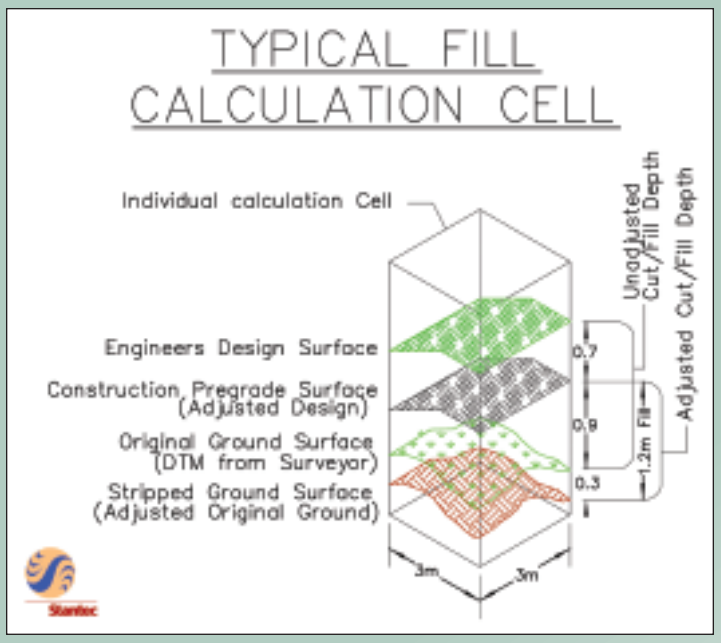

Figure 1.

The design surface (based on the grading design work by the engineer – Engineers DTM) is adjusted by a pregrade value that accounts for imported materials such as granular and asphalt and topsoil placement as well as displacement from pipes and basement footings (pregrade value for residential subdivisions is typically 0.8 m (average)). The difference between the adjusted design surface and the adjusted existing surface is multiplied by the cell area giving a cut/fill volume for the cell. This calculation is repeated for all the cells included in the calculation area boundary. Figure 2 illustrates that there are individual squares that go into making up a grid calculation for a single parcel (eg. lot or road section).

For the complete calculation, the entire area of the DTM is gridded and the results of the individual cells summed. Results can be subdivided based on bounded areas as desired (typically lots and roads). This results in an outcome that looks something like Figure 3. As you can understand from this explanation the DTM that you, the surveyor, supplies for the site directly influences the outcome of the analysis. Therefore, if due to a benchmark error or other factor your DTM surface is high or low, this outcome (all other items being correct) will be directly reflected in a correspondingly unbalanced site. This is your liability issue! Understanding the rest of the process as indicated previously allows you to keep your liability limited to that.

Now if the EW calculation just consisted of comparing the OG DTM and the engineer's DTM, life would be relatively easy. Unfortunately, the devil is in the adjustments that were mentioned and limitations in building design surfaces. Specifically, factoring into the adjustments is compensation for the estimated volume of imported materials to the site and soil volume changes associated with disturbance. We will examine these categories and what they are attempting to account for as well as some practical issues of actually completing the work of moving the dirt. To manage the site properly, as-built surveys need to be completed at three points:

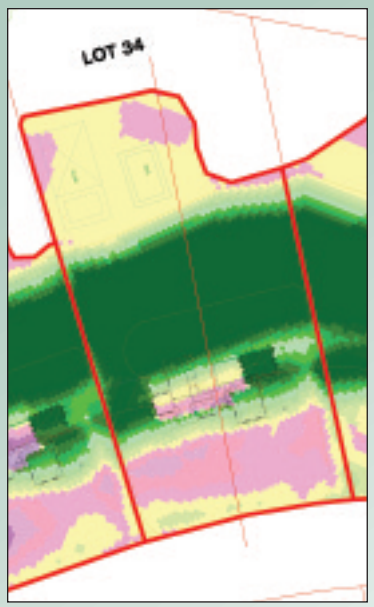

Figure 2.

- Following stripping of topsoil. *This confirms assumptions about topsoil stripping quantities.*
- Following completion of mass EW and prior to any servicing (roads and lots). *This confirms the calculations for mass EW. If the project reaches this point without imbalance and the survey confirms grades, your DTM was accurate (barring a mistake with the engineer's surface or comparison calculation).*
- Following completion of roads to base asphalt (lots only). *This confirms the correct pre-grade on the lots for builder turn-over. Any error in estimating the road pre-grade now resides in the lots as the roads and boulevards should be at their design grade.*

The third article in this series will delve into the details of completing "as-built" surveys.

The Engineers DTM

Just as the surveyor must collect site elevations and define the top and bottoms of slope, etc. to build a surface that closely duplicates reality, the engineer must select and manage design elevations that will build a surface that

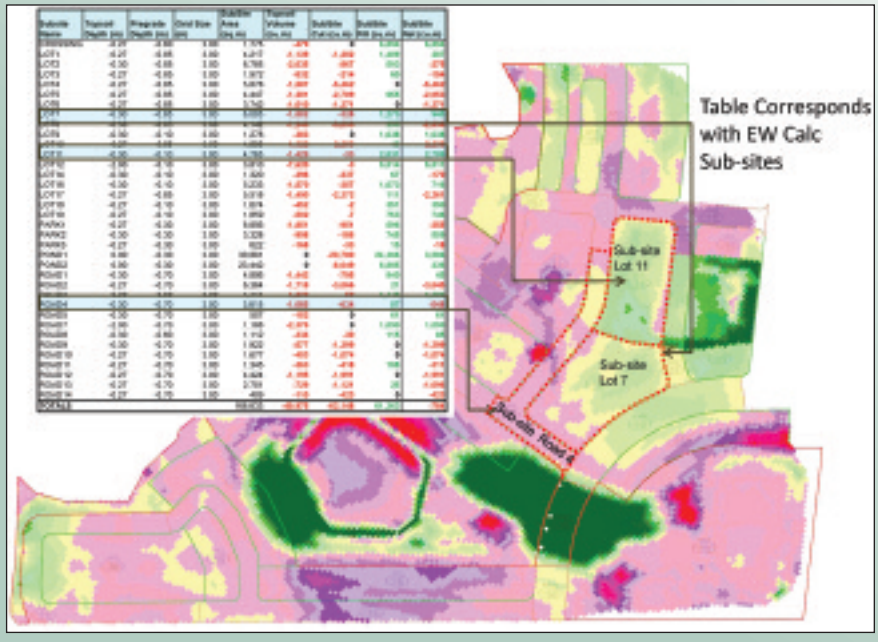

Figure 3.

closely approximates future conditions. If you examine the engineer's grading plans, you will see many items of grade information (i.e. house grades, swale grades, lot corners, centerline of road, etc.) Much of what is presented is dictated by the municipality and is not particularly conducive to building an accurate DTM surface. To manage the grades they should be layered such that particular data sets can be selected for the building of an accurate DTM. Typically, these will still not provide an accurate surface. For example on roads the centerline will have grades and so will the lot corners but missing will be the gutter and top of curb (except for some special circumstances). Thus, if you build the surface from the available points you have a shallow V (see Figure 4 – Green line) and the actual surface is not correctly represented.

There are many ways to correct this. Two options are; you can calculate a small pre-grade correction and factor it into the road balance line that corrects the volume calculation outcome or you can run a template on the road centerline that inserts elevation points on a hidden layer and ensure they are in the build for the DTM. My own practice was to remove the centerline points entirely to allow the surface to build flat across the road from lot corner to lot corner then include an adjustment to lower it to equivalency with the actual surface. This illustrates the issues at hand but, is not the end of them, so suffice it to say there is room for errors when it comes to the Engineers DTM. Although, typically, due to the density of points that must be correct (i.e. lot corners and centerlines) it should be modest.

Rest assured however massive errors are still possible and these can easily occur with pre-grade adjustments. The pre-grade may change several times in the course of a job design (i.e. lots are converted from singles having a pre-grade adjustment of 0.7 m to townhouses where the pregrade adjustment is 1.1 m) or the alignment of a trunk sewer is revised and the road pre-grades are not correspondingly adjusted, etc., etc. The list is practically endless. Basically, the commitments to the grading strategy occur early and many changes occur after that point which must be factored in to keep it updated. If through miscommunication and or misunderstanding or just plain omission these are not done, trouble is ahead as the calculation no longer matches the reality and the planned balance is out the window. This provides a single illustrative source of error but is far from the end of possibilities.

The Engineer's Adjustments

Topsoil Stripping Depth

Topsoil is not suitable for completing structural fill, which is a condition where the fill must support a building or asphalt road load. Accordingly, most of the topsoil on a site will be surplus as large areas are eliminated by this consideration. Typically it will be stockpiled and from there either exported offsite or reused on the site. Most importantly the volume of the stripped material must be allowed for in the EW calculations by the engineer. This depth/volume of topsoil is estimated using information collected by the geotechnical engineer from test pits/boreholes. This data however is sparse and may only consist of a dozen points for a sizable site. It is possible that unsampled areas may have less or more material for a variety of reasons including historic site grading or filling. A result of this is that average stripping depth may vary by several centimeters from the calculation assumption. This would mean a corresponding variance in the site balance volumes. The topsoil stripping survey is meant to evaluate actual results and confirm that they are in line with the calculation assumptions and to allow consideration of a correction strategy if they are not.

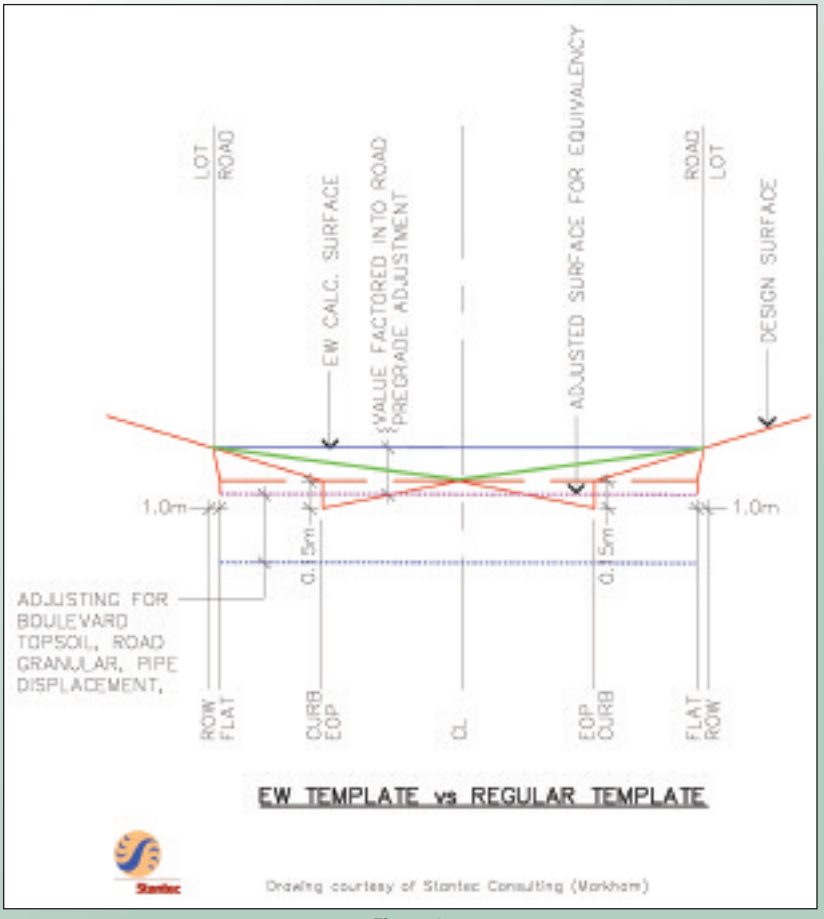

Figure 4.

Without a confirmation of stripping volumes, accusations attributing modest imbalances to topographic error are not valid. Note that a variation of 0.03 m from the estimated topsoil depth is not at all uncommon. This equals 300 m^3 per ha or for a 40 ha site 12,000 m^3. This is a noticeable amount of dirt if it ends up as a pile or hole. When spread over the site it is not so serious but since the site is put to grade as work progresses the former not the latter is the usual outcome.

Pre-Grade Adjustments

The pre-grade is a catch all term for a whole host of factors that are blended together in an attempt to posi-

tion the rough graded surface such that when site construction is complete the site is on grade without export or import. These are covered briefly under the following three headings:

Lots

The lots on a subdivision are subject to a variety of imports. The main items include clear stone for the footing, granular and asphalt for the driveway and topsoil and sod to green the lot. The volume of all these materials must be estimated and then combined with the excavation volume from the basement to set this value. Now if you knew what was being built on the lot and the builder's practices, this could be fairly accurately done. But, typically when the site balancing is being done the size of the house is not known exactly. There may be a variety of models with varying size and you do not know what sales will happen on what lots. The conditions (time of year) at the time of building may influence the quantities for use of stone, or granular for the driveways. Different builders also follow different practices. It is important to note that a miscalculation of the pre-grade shows up as an imbalance condition even if the rough grade has been verified by an as-built following site grading. Most importantly to understand from the surveyor's perspective is that this almost certainly means the problem is not attributable to the OG survey. Problems with the OG survey will make themselves known before the end of the site earthworks exercise if the proper as-built surveys are done. If they were skipped short of confirming a BM/TBM error you should be in the clear.

Roads

Roads are subject to the installation of services and the pipes and granular bedding required for them displace material within the road area (usually termed sewer spoil). Additionally, large volumes of granular material are brought in to build the road base for paving. These volumes are estimated by the engineer and the road is pre-graded about 0.7 m below centerline to compensate. Desirably, the grading of the site will be completed before any of this servicing starts and an as-built survey has been completed. As noted previously if the EW balance works out at this point you are off the hook for everything hereafter for your original DTM.

Since completion of the roads to base asphalt precedes the building activity on the lots, any engineer's error in estimating the road pre-grade will be displaced into the lot if surplus occurs. Alternatively, if a deficit occurs, material will be pulled out of the lots to finish the roads and the lots will be left low. In a typical subdivision, roads represent about 25% of the total area. So the quantities can be sizable. It also often occurs that road building is occurring late in the construction year and the sub-grade is soft. To strengthen it additional granular may be placed which was unanticipated in the original EW calculation resulting in an equivalent volume being displaced from the roads into the lots. This is why the pre-grade of the lots is checked by an as-built survey after the completion of roads to make sure they meet the builder's specification for pre-grade.

Soils Bulking

Many imbalances are attributed to this factor mostly, in my opinion, as a convenient cover for inexplicable results. Bulking does of course occur with material disturbance but my experience, which is primarily with the glacial till common throughout the GTA, is that this is generally a very small factor, maybe 1%. Other materials are more troublesome, specifically shale, which is fairly common out in the west end of the GTA. Once broken up by excavation activity its volume expands by about 20 to 25%. Shale excavation most frequently occurs with the installation of services and the adjustment for the road pre-grade which must be increased to account for its bulking. Occasionally, shale is a factor in the actual cut/fill operations of the overall site grading in which case the volume of shale cut must be estimated and factored in separately to balance the site. This involves estimating the shale surface (which is covered by soils of varying depth) and building a second surface from a few boreholes, a dicey estimate to say the least.

Contractor's Efforts

So far the article has dealt with the academics of the engineer's surfaces and adjustments that are made, of course all this is translated into an actual outcome by the contractor. I have had it pointed out to me that the machines (typically scrapers) can only grade to within certain tolerances; say 0.03m so that amount applied to the site area explains the imbalance. Alas, the error margin of the machine and operator is both positive and negative, so some areas of the site may be high but others are likely to be low and the truth is on a decent sized site they should be approximately in balance. I am not particularly well versed in the practices of construction layout and so will not elaborate in this matter, but, I can say with confidence that the number one thing to ensure a positive outcome for a project is to ensure that the contractor has verified the TBMs that the surveyor has established for the site. This gets it off to a start on the right foot (see also feedback on Article 1 below).

Conclusion

While the above is not exhaustive, you will get a sense of the complexity of adjustments which must be estimated by the engineer with limited information to achieve an EW balance. Consider also that this is before actual construc-

tion accuracy issues are factored in. Now, most people would consider these conditions and in their minds it is rationalized that this item is only accurate to within 0.02m and that item is only accurate to 0.03m, etc. and they mentally add them up individually and say its hopeless trying to balance a site. But I know that this audience, as students of least squares adjustments, will realize that each individual estimate is independent (for the most part) and so the errors within their margins are randomly positive and negative so that when summed they tend to cancel so it's not so hopeless after all, barring an improbable alignment of estimating errors resulting in a fringe outcome on the bell curve.

With this article I hope I have provided some insight to the liability you actually have and defense from the liability that may be offered to you. Asking some strategic questions can often clarify that without particular pieces of information there are simply no grounds to tie it back to surveyor error. When implicated it would be my advice to act quickly and aggressively to resolve the issue. Delay only aids selective memories and difficulties in tracking down documentation and information from involved parties and with that I will give the final words to your Insurance Advisory Committee:

> *The Insurance Advisory Committee has noticed a rise in claims related to topographic surveys used by engineers for earthworks calculations. Better communication between the surveyor and the engineer could have avoided some of these claims. The two items that are of concern to professional surveyors are accurate TBM's and an accurate representation of the surface at the time of the topographic survey. Engineers and contractors typically do not confirm the geodetic datum of the TBM's and in some cases do not check between TBM's or their relative accuracy to existing surfaces (i.e. paved roads, services, etc). Understandably, the accuracy of the original ground surface survey is dependent on the methodology, equipment used, time of year, and DTM generated by the surveyor. All of this should be included in a report to the engineer with the topographic survey deliverable. Having a NOTE on the face of the plan to identify any limitations of the survey (i.e. site conditions) and the importance of confirming the TBM elevations by those using the survey is a recommended practice.*

Points of Feedback on Article 1

The following points were provided by an interested contractor (who has his own concerns) and are worth noting.

- It is important that the surveyor that completed the topographic work and the contractor are working on the same benchmark. The legal surveyor should provide at least 3 vertical benchmarks around the perimeter of the site on fixed objects (say top of nut on a hydro tower or other permanent feature). The contractor is responsible to bring in their own Town/City benchmark from the information shown on the engineer's drawings and tie into these 3 TBM's to confirm vertical elevations are in agreement. This should be verified between the engineer, surveyor and contractor by the time of the pre-construction meeting. Work should not begin without it. *If these simple steps were followed and confirmed before work started the problems that do occur would be more than halved! Unfortunately, based on a variety of rationalizations this practice is not rigidly adhered too. I believe that part of the problem is that it is not a clear responsibility as to who should do this. If not dealt with by the engineer, do your part and document it thoroughly.*
- In the case of site buildings the footings/floor elevations must reference the same TBMs to avoid any vertical discrepancies.
- Everybody is moving toward GPS these days, but we favour the line of sight level loop method when bringing in a benchmark to the site. *Nothing beats closing the loop.*
- We agree with the point that the contractor should report a discrepancy between the engineer's and contractor's OG topo, but it will be hard to determine which is correct if both topo specific spot elevations are in different locations. Checking into the TBM's will make sure everybody is working on the same page as far as the starting vertical elevation conditions. *It will almost invariably be the case that individual points do not coincide for comparison however I believe that a superior method is the comparison of the OG surfaces. For earthworks the accuracy of any one point (other than TBMs) is within reason not particularly important. By looking at the two DTM surfaces you gain an overall view of elevation differences and most importantly the volume between them. If desired the volume divided by the area gives an average discrepancy for any particular point on the surface. This comparison can be completed by the engineer within a day of receipt of the contractor's topo and should precipitate immediate actions and alerts if not in very close agreement (<0.015 m or 150m^3/ha).*
- We currently use a quad ATV equipped with GPS to do the bulk of the original topographic survey so we can have a greater amount of shots without increasing cost and time. Our surveyors also walk the site to manually pick up additional points to define the top/toe slope break lines which we use to create our final DTM surface. *(a good strategy of high coverage and control)*

Hopefully you have found something of value in the foregoing material. Should you have any feedback please e-mail your thoughts to **mcgill_dev_services@rogers.com.** If I receive some good points, questions or tips, they will be presented in a final article. Names will be changed to protect the innocent so do not hesitate to send material in.