Mobile Point Cloud Assessment for Trench Safety Audits

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Abstract –

Fatalities resulting from cave-in hazards during excavation work in the United States account for 48% of the trench fatalities in construction every year per Occupational Safety and Health Administration (OSHA) data. Recent trends indicate that fatalities from trench and excavation hazards in the US are increasing. Often the experience of safety inspectors and/or the designated competent person (CP) for trenching and excavation is vital when assessing sloping measurements with approved engineering survey tools. The degree of accidents, however, allows the conclusion that proper assessment and/or protection of excavation sites is not performed sufficiently in the field, or safety coordinators and/or adequately trained CPs are not on hand when needed. While existing assessment processes and protection methods are reviewed for potential improvement, this paper proposes a new compliance assistance prototype that incorporates state-of-the-art technology. The proposed prototype creates: (1) mobile field data acquisition with low-cost photo cameras to capture point cloud surveys of the as-built conditions of trenches, and (2) computational data processing to automatically extract trench height, width, and slope values. Early results to field-realistic experiments promise useful applications of the developed prototype for safety coordinators or adequately trained CPs.

Keywords –

Cave-in hazards, hazard recognition, mobile application, photogrammetry, point clouds, risk management, safety education and training, remote sensing, trench safety.

1 Introduction

The U.S. Department of Labor requires cave-in protection by sloping, shoring and/or engineering controls when an excavated trench is five feet or deeper. If sloping is the designated compliance method, compliance is compared to the requirements in OSHA Subpart P – Excavations [1]. Often the experience of safety inspectors and/or the designated competent person (CP) for trenching and excavation is vital when assessing sloping measurements with engineering survey tools. Current field assessment methods for sloping compliance and the number of accidents, however, allow the conclusion that proper assessment and/or protection of excavation sites is not performed sufficiently in the field, or safety coordinators and/or adequately trained CPs are not on hand when needed [2].

Therefore, this paper proposes an engineered compliance assistance prototype that improves existing trench assessment and field training using mobile point-cloud data acquisition and computational processing for trench sloping assessment. Although the scope of the presented work is limited to the development and testing of the developed prototype, it is envisioned that its application has potential to guide specific toolbox talks and immersive OSHA CP trench and excavation training. Demographics to be reached with this prototype include OSHA CP training centers in the U.S. and worldwide, construction and utility stakeholder organizations, and the twelve most common industries involved in trenching and excavation work per OSHA data [3].

2 Background

The background review concentrates on the identification of the key issues in trench safety: (a) the standards of practice and an analysis of available statistical data on trenching- and excavation-related injuries and fatalities in the US, (b) the current practice for assessing trench compliance with sloping standards, e.g. as outlined in OSHA Subpart P, (c) the reasons behind the current approaches, and (d) the potential of research with emerging technologies to improve safety in trench work.

2.1 Trench definitions and types of violations

A trench in construction is, according to OSHA definitions, defined as a narrow underground excavation that is deeper than it is wide, and no wider than 4.5

meters [1]. While the width of a trench is measured at the bottom, excavated trenches provide predominantly temporary access to buried underground utilities or structures. A trench is a confined space with many special problems.

Per an OSHA Regulatory Review [3], excavation fatalities may result from a variety of accident types, including cave-ins, machine accidents, falling objects, electrocution, car accidents, explosions or fires, falls, drowning, and asphyxiation due to noxious fumes. Distribution of fatalities by cause of death between 1990 and 2000 indicated that 48% of fatalities in excavations occurred by cave-ins. They often are caused by piles of excavated material placed too close to the trench's edge, no protection against the collapse of trench sidewalls, no proper means for workers to safely exit the trench, employees working underneath the operating bucket of a backhoe removing soil from the trench, and no protective equipment, including use of trench boxes or helmets, for workers. Other occupational risks in trench-related work are falls, electrocution, being struck by falling objects or a backhoe, and hazardous atmospheres causing fires or poisoning of workers.

Such trenching-related injuries continue to plague the construction industry, despite the availability of well-known and effective control methods, such as benching and sloping, shoring, and trench boxes and shields. Although trench collapses are not the most common cause of construction deaths, the collapsing weight is likely to result in death or serious injury within minutes [4]. In addition, other workers are often at risk and die trying to conduct rescues.

2.2 Safety statistics and current practice

Excavation work for trenches is responsible for approximately 5% of the more than 1,100 fatalities in the US construction industry every year. Out the total number of trenching and excavation accidents, the percent of cave-in hazards leading to worker fatalities occurs on 48% of sites from OSHA data [2,3]. Most of these accidents occurred in the Standard Industrial Classification (SIC) system code No. 1623: water, sewer, pipeline, and communications and power line construction [5]. The next nearest industrial code was No. 1794: excavation work.

For some of these reasons, the U.S. Labor Department's Occupational Safety and Health Administration (OSHA) requires cave-in protection by guarding trench sides that are not shored or otherwise supported when the trench is five feet or deeper.

Often the experience of a safety inspector and/or designated CP is needed to assess the situation when such safety features are required. The prevalence of accidents, however, allows the conclusion that proper inspection of excavation sites is not performed accurately or safety coordinators are not on hand when needed.

The National Institute of Occupational Safety and Health (NIOSH) stated between the years 1976 and 1981 excavation cave-ins caused about 1,000 work related injuries each year. Of these, about 140 resulted in permanent disability and 75 in death (25 per year). These work fatalities in excavations accounted for nearly 1 % of all annual work-related fatalities [6]. Although better safety training methods and enforced regulations have been developed in recent years, the overall safety performance for trench work in the United States since then has not improved, may be even worsened due to more work hours accomplished.

In 542 trenching and excavation fatalities from 1992 to 2001 the average age of the decedents was approximately 38 years [5]. The same study reports that of the fatalities, 47% occurred among employees of companies with less than 10 workers, and 70% occurred in companies with less than 50 workers. The largest proportion of deaths occurred among construction laborers. Among the decedents, the average length of employment with their employer was 6.7 years, 16% of the deceased workers had been with their employer for less than 1 year.

Conditions that contributed to a fatal event were missing trench protection in 66% of all fatal deaths, lack of supervision and daily inspections in 52% of all fatal cases, no training provided (52%), spoil pile within two feet of edge (41%), and rain or standing water (34%) [7].

In addition, in the years from 2000 until 2009, 350 workers in total died in trenching or excavation cave-ins. Most incidents involve excavation work or “water, sewer, pipeline, and communications and power-line construction” [8]. Results from an analysis of OSHA data from 1997−2001 showed that 64% of fatalities in trenches occurred at depths of less than 10 feet [9]. Lack of a protective system was the leading cause of trench-related fatalities in a review of OSHA inspections [7].

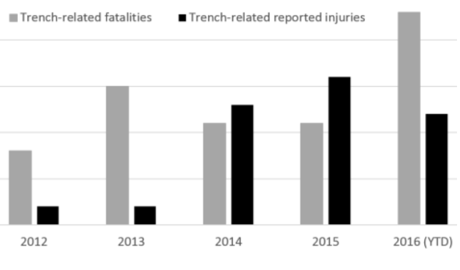

Figure 1. US trench injuries and deaths [10]

Most recent data from OSHA from 2012 to 2016 indicates that trenching injuries and deaths have been trending upward as noted in Figure 1. Trench related deaths and injuries have risen in the US from 8 in 2012, to 23, and 2 to 12, correspondingly, in 2016 (at the time this data was surmised) [10]. Note, depending on the type of material one cubic meter of soil can weigh up to 1,700 kg, which means trench collapses are difficult to survive. Injuries from trench collapses happen less often than fatalities.

2.3 Reasons on existing injuries and fatalities

These statistics and specific examples demonstrate that injuries and fatalities associated with trench collapses and other excavation hazards continue to occur in alarming numbers despite regulations and consensus standards which describe engineering controls, protective equipment, and safe work practices to minimize hazards for workers. Several researchers identified mainly the need for effective worker training before work starts and a CP onsite [11-14]. Although education and training show to be a worthwhile investment, reasons for the failure of current best practices still come from sources related to human decision making, such as:

- The CP is not on hand or misinterprets the site excavation conditions. Subsequently a cave-in can happen any time.
- The CP does not re-inspect the trench before every shift (as the excavation rule states after anything that can increase hazards, such as every rainstorm, vibration or heavier loads, trench walls move or get heavier, causing cracking, scaling, or bulging).

The consistent absence of evidence of compliance with existing regulations suggests that employers are either (1) unaware of the existence of the OSHA standards, (2) misinterpret the requirements of the standards, or (3) lack or fail in supervision.

2.4 Regulations for trench work

Regulations for trench work exist in many countries and in the US since the establishment of the Occupation Safety and Health Administration (OSHA) in 1970. Many of them are practiced to protect workers, for example systems that provide sufficient strength to withstand moving ground [15]. The OSHA Subpart P was established to protect workers in trenches and all excavations in the Code of Federal Regulations: 29 CFR 1926.650,651, and 652. The confined space standard is 29 CFR 1910.146. These special rules try to protect workers in all excavations, including trench work. Some of the general requirements of Subpart P that are relevant to this study are summarized [1]:

- Determine soil classification with manual and visual tests before work begins.
- Install protective systems in excavations deeper than 5 feet in any type of unstable or soft material and soil, but except solid, stable rock. Slope or bench trench walls and faces, shore, sheet, or brace trench walls with supports, shield trench walls with trench boxes, allow safe access using ladders, ramps or stairways.
- Appropriate shoring, shielding, or sloping requirements for all excavations deeper than 20 feet (except those in unfractured rock) must be determined by an engineer qualified to take prompt corrective measures to eliminate safety hazards. Such a CP must be capable of identifying existing and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous, or dangerous to employees [4].
- Soils can be classified as Type A, Type B, or Type C. Type A soil is the most stable soil in which to excavate. Type C is the least stable soil. It's important to remember that a trench can be cut through more than one type of soil.

If sloping is utilized as the means of compliance by employers, allowable slope angles for excavations less than 20 feet based on soil type and angle to the horizontal are listed in Table 1 [16]:

Table 1 Allowable slope angles for excavations

Soil type	Max. height/depth ratio	Max. slope angle
Stable Rock	Vertical	90 degrees
Type A	¾ to 1	53 degrees
Type B	1 to 1	45 degrees
Type C	1½ to 1	34 degrees

Soil can also be judged to be cohesive or granular. Cohesive soil contains fine particles and enough clay so that the soil will stick to itself. The more cohesive the soil, the more clay it has, and the less likely a cave-in will happen. Granular soils are made of coarse particles, such as sand or gravel. This type of soil will not stick to itself. The less cohesive the soil, the greater the measures needed to prevent a cave-in.

Excavations (including trenches) adjacent to backfilled areas or subjected to vibrations due to proximity from railroads, highway traffic, or operation of machinery shall have additional shoring and bracing precautions taken. Keep heavy equipment away from trench edges, knowing underground utilities prior excavation, keep excavated materials at least two feet away from trench edges.

Requirements under OSHA Subpart P include that a CP inspect the trench and excavation sites for potential cave-in hazards, and verify protective measures are in place. CP training for trenching and excavation, and OSHA 10 hour and 30 hour classes with training curriculum on trenching and excavation, are conducted nationwide in the US.

2.5 Existing challenges

In 1985, the U.S. Department of Labor's OSHA initiated a national emphasis program in trenching and excavation because of the continuing incidence of trench/excavation collapses and accompanying loss of life [15]. The agency had determined that an increased OSHA enforcement presence at worksites where such operations are being conducted was warranted. Trenching and excavation work creates hazards to workers which are extremely dangerous. Compliance with OSHA construction standards applicable to such operations is frequently bypassed because of economic pressures, a belief that compliance is unnecessary or an expectation that these short-term operations will go undetected. OSHA believed that the rate of deaths and serious injuries resulting from trench/excavation accidents (mostly cave-ins) could be significantly affected by a concentration of compliance resources within the area of trenching and excavation operations.

The OSHA regulations in Subpart P are usually established on national level and for practical reasons are often implemented with regional training centers in the local industries. In the State of Georgia, for example, OSHA, Georgia Institute of Technology and ASSE (American Society of Safety Engineers) have formed a Trench Safety Task Force that will arrange safety training courses to authorities overseeing excavation work to increase their awareness of the trenching hazards and enable them to identify unsafe trench conditions using a safety fact sheet [3].

Though currently, training and related curriculum in CP and OSHA 10/30 hour classes is primarily distributed through hard copy documents and PowerPoint presentations. Virtual and/or augmented reality have not been widely adopted for trenching and excavation CP curriculum in the world [17]. There is not an annual training requirement for CP refreshers.

In addition, OSHA covers most private sector employers and workers in all 50 US states, the District of Columbia, and the other US jurisdictions either directly through OSHA or through an OSHA-approved State Plan. 22 states or territories have OSHA-approved State Plans that cover both private and public sector workers. State Plans are OSHA-approved job safety and health programs operated by individual states instead of federal OSHA. Section 18 of the OSH Act encourages states to develop and operate their own job safety and health programs and precludes state enforcement of OSHA standards unless the state has an OSHA-approved State Plan. While OSHA approves and monitors all State Plans and provides as much as 50 % of the funding for each program, enforcement is not always possible. State-run safety and health programs must be at least as effective as the federal OSHA program. The State of Oregon (OR-OSHA), for example, has for the most part adopted the federal trenching and excavation regulations into their code. In the State of Washington, the labor and industries division of Occupational Safety and Health [18] has adopted the federal code, except for sloping, benching, shoring, and/or shielding requirements. Herein, WA-LNI-DOSCH requires protection for a depth of 4 feet or more, as opposed to 5 feet per federal OSHA

2.6 Trench assessment questions

The following overview is a summary of the OSHA Technical Manual on trenching and excavation assessment and inspections. The list of tasks to perform include an OSHA inspector to ask relevant site assessment questions (OSHA Technical Manual, Section V: Chapter 2) [19]. During first and subsequent visits to a construction or facility maintenance location, the compliance officer (or the site's safety officer or other CP) may utilize the following questions when investigating a site for compliance with OSHA Subpart P. Note that imminent danger conditions may require that employees are removed from exposure conditions as soon as possible. To understand the questions easier, a summary flow chart for the worksite assessment on trenching and excavation inspections is provided (Figure 2).

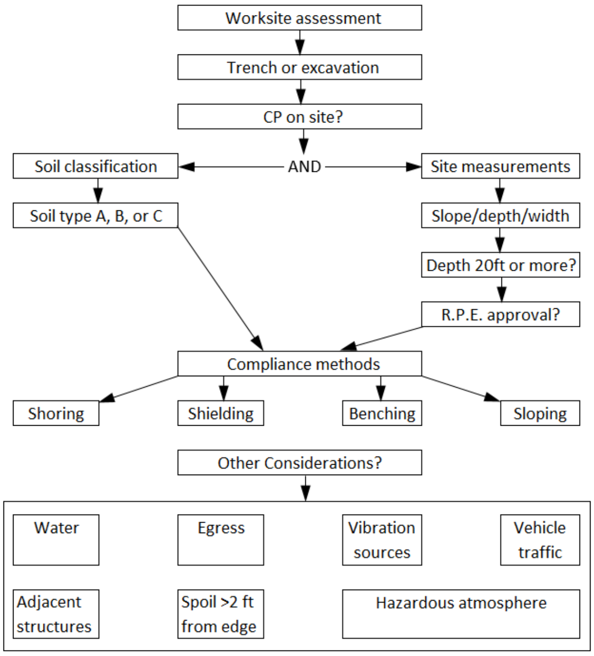

Figure 2. OSHA's Trench and Excavation Inspections – Worksite Assessment Process

A CP is someone who can identify conditions that are hazardous to employees and who also has the authorization to correct these hazards. R.P.E. refers to a Registered Professional Engineer. Spoil represents soil that was excavated from the trench. In addition: One cubic yard of soil can weigh as much as a car, 1,700 kg, and comes in many varieties. Some types of soil are stable and some are not. Any excavation deeper than 20 feet must use a protective system approved by a professional engineer. For all excavations, a CP must conduct a full investigation every day, or when any trench conditions change, to identify and remove any potential hazards.

2.7 Trench compliance assessment

Depth, dimension, and sloping assessments are conducted by OSHA compliance staff and CP with engineering survey rods, "plumb bobs", tape measures, and/or inclinometers. When calculating compliance with Subpart P, OSHA compliance staff utilize existing templates to determine the distances a trench and/or excavation may be out of compliance. One example is a Trench Calculation Tool (TCT) requiring manual input of values such as trench width (at the top of the trench), heights (of the trench side walls), and slope (angles of trench side walls), before automatically determining distances a trench or excavation is out of compliance for type A, B, and/or C sloping requirements. The template is utilized for compliance scenarios involving simple slopes, multiple benches, and one sided excavations.

The Trench Calculation Tool (TCT) was created in OSHA Region V in Wisconsin, and was designed as an Excel spreadsheet to facilitate determination of whether or not trench and excavation sloping assessed on work sites is in compliance with OSHA Subpart P – Excavations. While it is not standardized among all OSHA offices in the US, it was designed as a best practice to facilitate calculations.

In this example, manual measurements (in foot) are provided for an imaginary company AGJT Plumbing Inc. The height, angle and width calculations would be provided from the OSHA compliance officer via manual measurements in the field using engineering survey rods and inclinometers. In this case, a simple slope trench or excavation assessment and corresponding sloping calculations are illustrated in Figure 3.

The West side of the trench (left side in the Excel spreadsheet) was indicated has having a sloping angle of 80 degrees, with a height z of 5.6 ft. The height of the East side of the trench was assessed 5.7 ft with an angle of 85 degrees. The top width of the trench was 5.7 ft. These are the only compliance officer measurements required for entry in this assessment tool. At the top of the TCT, the top width calculations illustrate that the trench is out of compliance for short term A (indicated as A***), A, B and C soil; these distances are provided as 4.1, 6.9, 9.7, and 15.3 ft. At the base of the TCT, distances are provided for the respective sides being out of compliance. For the West side, this is 1.8, 3.2, 4.5, and 7.3 for A***, A, B, and C; for the East side, this is listed as 2.3, 3.8, 5.2 and 8.0, respectively. If these measurements were encountered by an OSHA compliance officer during an inspection, typically the employer would be cited for sloping deficiencies in OSHA Subpart P, assuming no other protective measures were utilized in the trench or excavation.

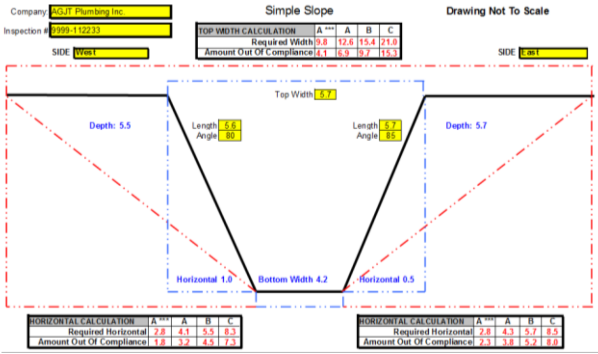

Figure 3. Trench Calculation Tool (TCT) [values in foot] which is utilized by some OSHA offices in the U.S.

3 Method to generate and analyze continuous functions from mesh, point cloud, and photo data

The process of using pictures of a trench to calculate its depth, width and slope angles is as follows:

Several methods exist for generating referenced point cloud data of a simple slope trench. Due to the easiness in data acquisition, photogrammetry instead of laser scanning devices was utilized. While latter choice tends to be more accurate, their cost (i.e., rental or purchase, installation time) is high. Cameras instead are easy to operate and an already used instrument of CPs to document site conditions. Moreover, camera-based photogrammetry delivers textures that may be used in later applications, such as visualization and training. One disadvantage of photogrammetry is the dependence on a larger number of photos.

Photogrammetry consists of two steps: camera data acquisition and software processing. First, depending on the size and shape of the point of interest, pictures were taken with a single-lens reflex camera (Canon EOS 6D, focal length 28-135 mm variable zoom lens) such that a processing algorithm can construct overlapping features (an estimated 60%) between the individual shots. It is important that both the environment and the settings of the camera remain similar for all pictures to ensure optimal conditions during processing.

Camera positions are then estimated out of all the pictures, using focal length as a reference. Although a standard procedure should be followed, taking several dozens of pictures for a simple trench needs minimal training. Exposure and aperture control are the most important variables to consider. Images should not be over- or underexposed and the depth of field should be sufficient, leaving important features sharp, while blurring the unimportant background. Also having a measurement of reference inside the pictures is important to later scale the model to real world size, for example placing a folding ruler in the point of interest is a good practice to follow.

There are several photogrammetry software applications available on the market, paid and open source. This study used the commercial Agisoft Photoscan (AP) software for creating and processing the raw point clouds from photos of the same point of interest. It also generates detailed static meshes. AP uses CPU and GPU processes for algorithmically working on the supplied pictures. Adjustment and adaption still needs minimal manual modification to the settings.

The first step is the aforementioned picture mapping process. The result is a sparse point cloud of the trench (Figure 4). While it is missing features, it provides an intermediate impression on what the result will look like. A dense point cloud is created in the following step. They represent the point of interest at a higher resolution (Figure 4).

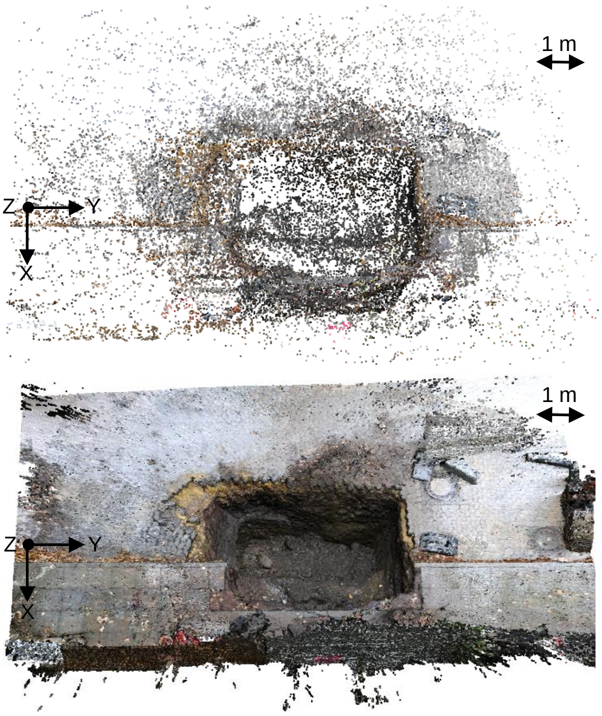

Figure 4. Plan views of simple slope trench: sparse (top) and dense (bottom) point clouds

As soon as the dense cloud has been generated, AP creates a mesh out of the data. From this dense point cloud a static mesh is generated. Meshing will reduce the highly detailed point cloud to a simplified model consisting of vertices of the faces of the mesh. While keeping the essential information for the desired trench slope assessment, the reduction to fewer points allows a user to work with the data set more easily. Optionally, textures can be mapped by projecting and merging the pictures from the first step onto the generated mesh. Scaling and orientation should be applied as the final step to get an accurate real-world representation. Latter is required to calculate trench height and width, whilet he computation of angles is independent from the scale.

After generating the static mesh, a custom application processes the data further. MeshLab® decimates the static mesh hence reducing the number of vertices and therefore the required computational power. Important to note is that the decimation process deletes vertices and interpolates between coordinates. This may lead to possible loss of detail, especially when precise measurements from a trench are needed. For example, a too simplified function may falsify the measurements whereas, on the other hand, further computational time is added. Deciding on the smoothing parameter requires experience. With enough training though, the smoothing process could be automated (part of future work).

The vertex with the lowest z-value (height of a trench) is taken as a reference to create a cutting plane through the mesh. The cutting plane is perpendicular to the y-axis (depth of a trench) and parallel to the x-axis (width of a trench). Nearest vertices within a manually-set δ value (e.g., 5 inches in both directions on the y-axis) are projected to the cutting plane resulting in a line of two-dimensional points $Set_{CuttingPlane}$. Points with duplicate x-coordinates are omitted to create the basis for a continuous function.

All points of $P_i \in Set_{CuttingPlane}$ are are sorted from their lowest to their highest x-values and clustered for a similar z-value. The developed clustering algorithm requires input of $Set_{CuttingPlane}$, hBuffer, wBuffer, minWidth, minHeight, and maxHeight. The z-axis is defined manually for now, but could be defined as the range from the lowest to the highest z-coordinate value. The algorithm inputs, except for minHeight and maxHeight, are created by loops and range from 0.1 m to 0.5 m. A table of results can be compared. While minHeight and maxHeight require manual input for now. The z-axis from minHeight to maxHeight is now divided into n intervals with a height of hBuffer*2. All points P_i that reside inside the same z-interval are clustered. The resulting clusters are called layer clusters (see Figure 5, top right). If two consecutive points inside one cluster have an x-value greater than wBuffer, this cluster is divided into two. From all remaining clusters those are eliminated that have a range on the x-axis smaller than minWidth. As layer clusters can intersect on the x-axis, some layers get clipped by removing the points of each layer cluster which intersect with the previous layer cluster. Inside each of the remaining clusters the z-value of every point is set to the average z-value of the whole cluster to eliminate all asperities (see Figure 5, bottom left). After this smoothing process, the clusters can be reduced to a line which is spanned by the two points with the corresponding lowest and highest x-values inside the cluster. These reduced clusters are now unified into a set $Set_{Simplified}$ (see Figure 5, bottom right).

At this point the method requires five points P_{lte}, P_{lbe}, P_{rte}, P_{rbe}, $P_{lowest} \in Set_{Simplified}$ to calculate the height, depth and slope values of a (single slope) trench:

- P_{lowest}: The point in the trench with the lowest z-value.
- P_{lbe}: The bottom edge on the left slope.
- P_{lte}: The top edge on the left slope.
- P_{rbe}: The bottom edge on the right slope.
- P_{rte}: The top edge on the right slope.

Depending on the trench type P_{lbe} and P_{rbe} can also be equal to P_{lowest}. For simplicity, it is assumed that P_{lte} and P_{lbe} are the points P_i, $P_{i+1} \in Set_{Simplified}$ where the z-difference between P_i and P_{i+1} is the greatest and the z-value of P_i is higher than the z-value of P_{i+1}. Likewise, P_{rte} and P_{rbe} are the points P_i, $P_{i-1} \in Set_{Simplified}$ where the z-difference between P_i and P_{i-1} is the greatest and the z-value of P_i is higher than the z-value of P_{i-1}. The remainder of the developed algorithm is basic trigonometric and geometric calculations. It leads to the desired angles, height, and width of the slope.

4 Experiments, results, and discussion

The same trench example outlined earlier (Figure 4) is used to validate the process. Figure 5 displays $Set_{CuttingPlane}$. Consecutive points in this set are connected for better understanding, though the set is not defined as a mathematical function. Figure 5 shows the intermediate steps from the raw data to $Set_{Simplified}$ with marked height and width of the trench.

In the presented case, hBuffer was set to 0.1 m and minHeight to the minimum y-value of $Set_{CuttingPlane}$. maxHeight was 0. The interval was divided into 9 layers whereof each covers a y-interval of 0.2 m. These sets are called layered clusters. The inputs wBuffer (= 0.1 m) and minWidth(= 0.1 m) increased the number of clusters to 10. Clusters were clipped and smoothened in the following according to the algorithm explained in Section 3. The resulting set of points, $Set_{Simplified}$, contains merely 20 points from initial 890 points in $Set_{CuttingPlane}$. The red line in Figure 5 visualizes the width whereas the blue line shows the trench depth.

For the selected cutting plane the algorithm calculated a width of 3.0 m, a height of 1.91 m, and angles of slope of 85.6° on the left slope and of 89.1° on the right of the trench. Compared to the manual assessment (trench width entered in Figure 3 is 5.7 ft or 1.74 m) the result of the proposed method differs by +72 %. This rather large difference is due to a reading error of the CP during the manual assessment (while the CP meant 3 m or 8 ft for the width of the trench, he selected 2 m or 5.7 ft). While the measurement of the proposed method (3.0 m) is -0.1 m or -3% off of the ground truth, both measurement methods concluded that the examined trench requires protection should a person need to enter it.

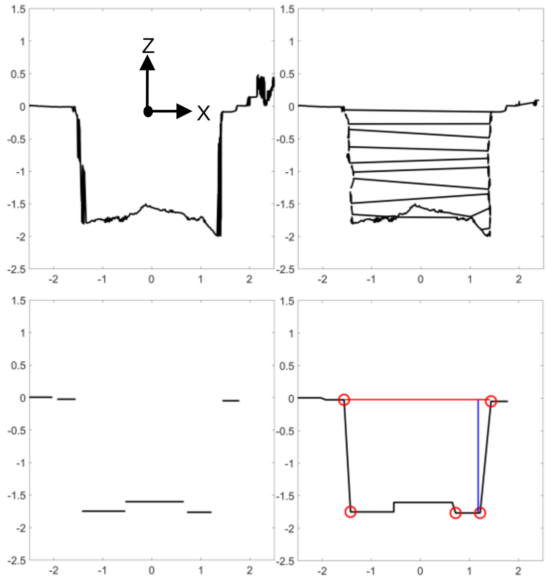

Figure 5. Cross-sectional views [in meters]: Original raw data (top left), layered clusters (top right), smoothened, reduced layer clusters (bottom left), identified points P_{lte}, P_{lbe}, P_{rte}, P_{rbe}, P_{lowest} and automated measurement of the width and height of a simple slope trench (bottom right) (horizontal axis: x-values, vertical axis: z-values)

5 Conclusions

While trenches pose a considerable risk to the life and health of construction workers, manual inspections dominate the practice. The proposed compliance assistance prototype has the potential to improve sloping calculations conducted by competent persons and regulatory compliance staff in the field. By utilization of mobile point cloud data acquisition and processing applications, inspectors and competent persons will have the ability to more rapidly assess the compliance of simple slope trenches according to OSHA Subpart P requirements. In addition, through the utilization of a mobile device, compliance staff standing on the edge of a trench during compliance activity will be protected from potential falls.

Future research might incorporate the elements of the findings into a virtual environment (VE) or virtual reality (VR) [20]. Similar to Wang et al. [21] that converted point cloud data of embankments of a deep excavation project into parametric objects, generated trench objects might serve in three-dimensional worlds as well. Such worthwhile opportunities would offer site-specific immersive training tools in competent person training sessions and site specific toolbox talks. They could supplement or replace existing paperwork and a yet PowerPoint-dominated OHS educational curriculum.

Disclaimer

While this paper is proposing an OSHA compliance prototype, note that the agency does not test, approve, certify, or endorse any equipment, product, or procedure, including machine design and risk assessment techniques.

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