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LASER TECHNOLOGY APPLIED TO EARTHWORKS.

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1. - INTRODUCTION.

In order to achieve a good finish for the surface when building a layer of road way, good quality for the grade line for the underlying layer is vitally important. Aware of this fact, the authorities are becoming ever more demanding as regards the tolerance levels for finishing levelled surfaces, sub-grades, bases and embankments.

The now well-known system for guiding motor graders by means of ultrasonic, in the operations for smoothing, ousted the traditional system of stakes, offering interesting improvements as regards to the quality of the finished surface, costs and yields.

The system based on laser technology offers even more for improving the quality of the end result, allowing lower tolerance levels and better evenness for the surface, a significant saving in manpower and a greater increase in productivity.

In works for smoothing layers of grade on the new runway for Barajas Airport the new laser-guided method was incorporated for the motor graders for the levelling, which especially appropriate for large surfaces, with excellent results.

The laser system is suitable for dealing with a large range of needs and a wide variety of applications, from which the following stand out:

- Airports.
- Roads.
- Dams.
- Platforms and Houses.
- Water treatment plants.
- Waste treatment plants.
- Canals and trenches.

In any case, the work to be executed should be analysed in order to make sure that "Laser Control " is the right tool. One of the conditions for applying laser control, is that it should involve a flat surface, this surface may be a completely flat pavement or have a slight slope in one or two directions; but in this case the slopes must be constant and straight in the area where it is planned to use the control.

2. – BRIEF DESCRIPTION OF THE SYSTEM.

Fig. 2: Panoramic view earthworks using the laser system with motor grader, emitter and target levelling-rod.

On the motor grader, and on both sides of the blade, two motorised electric receivers are mounted on two guide masts, which, when properly calibrated, tell the control system whether the blade is cutting too high, too low, or at the right height, continuously correcting the error by working the electric valve control box.
The fixed equipment consists of a swivel-head laser emitter that defines a virtual plane, fitted with automatic and adjustable levelling on a slope in two orthogonal directions (hence it makes it possible to adapt to a longitudinal

slope and another transversal one), the virtual plane defined by the laser is parallel to the future plane for the pavement, although at a different elevation.

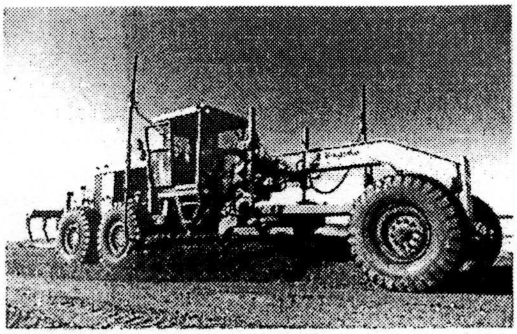

Fig. 3: close-up of grader with receivers mounted on the blade.

It is also equipped with a manual checking device, mounted on a telescopic surveying target levelling-rod, which is used for both the prior calibration of the machine, and for checking the result of the operation for smoothing straight away.

The laser system is compatible with the now common-place ultrasonic system. This compatibility allows many combinations, such as, for example, controlling the height with the laser on one side and the automatic reading of the difference in the grade level with the control box on the other side; or controlling the height on one side with the ultrasonic (copying from a fixed reference), and in the other side controlling the difference in the grade level with the laser sensor, thus avoiding the influence of gaps; etc.

3. - ADVANTAGES AND DRAWBACKS FOR THE SYSTEM.

The main advantages of the laser with respect to the ultrasonic systems are:

1. Taking a reference from outside of the work are and periodically checking it ensures that you are working properly.

2. Savings in labour and surveying equipment.

3. Reduction in the time for producing field data in the technical offices.

4. As compared to the ultrasonic system, there is no need to perform a general calibration every day on the equipment mounted on the machine.

5. The excess of material in the smoothing and spreading work makes it slip and unbalances the ultrasonic system, something that does not arise with the laser.

6. There is less influence of the gaps in the machine in the end result.

7. There is no possible interference with radio systems (Radar in the case of airports)

The advantage of the ultrasonic system as compared to the laser system lies in the possibility producing surfaces with differences in the grade level and longitudinal and variable slopes and suffers less from the influence of atmospheric conditions, especially heat, strong winds and the presence of obstacles between the emitter and the receiver.

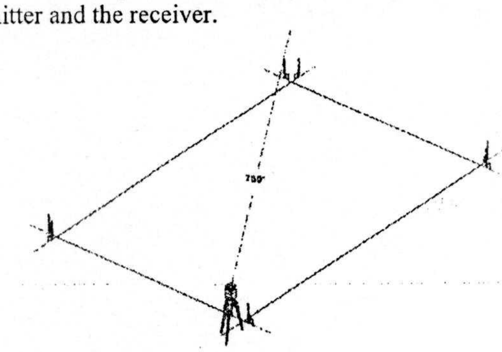

Fig. 4: View of the execution of earthworks with a laser system

4. RECOMMENDATION FOR SETTING UP THE LASER EMITTER.

In order to achieve the quality and the yields required in the corresponding works, a number of recommendations must be followed with respect to the installation of the emitter.

It is advisable not to place the emitter over 230 m. away from the pavement for the works, since as the distance to the laser emitter increases, the degree of accuracy will fall. Vibration on the terrain due to the work of the machinery near to the emitter, error of calibration, curvature of the earth, movement of the laser due to the wind, are just some of the factors which will be most important to take into account as the distance increases. It must always be borne in mind that the laser beam is a beam of light that travels across the atmosphere and some atmospheric conditions may be a cause of refraction, since it travels through the air. All these factors grow worse when the distance to the laser increases. In order to minimise them, the work are should be as close to the laser emitter as possible in order to maintain proper tolerance levels and yields.

On small surfaces it is preferable to place the laser outside of the work area. This way it ensures that the devices do not interfere with the works machinery and so it will not be necessary to set up the whole device again for the levelling in the area they cover.

On large surfaces placing the laser in the centre of the working maximises the surface that may be levelled and minimises the distance to the laser. It might be necessary to level one area of work and then move the laser over and over again until finishing the whole surface. In this case it is justified to place the laser on the pavement through the increase in the effective surface area that may be levelled without moving the device.

When different adjoining pavements are levelled, it is advisable to place the laser in a position that will allow several pavements at the same time, without having to move the device, hence it saves the time needed for setting up the device on each one of the pavements.

During the progress of the works it is usually necessary to adjust the emitter, that is why it is important to place it at the minimum height possible, if the emitter is kept low, *"within reach"*, adjustments may be made and the level may be changed more easily. The laser emitter and the receivers on the machine shall also be much more stable. On windy days it is advisable to anchor down the tripod to protect the laser from the wind. The advantages of keeping the emitter low outweigh the momentary loss of the laser beam caused by the passing of the machinery, hence there is no reason why the laser emitter should be above all the machinery in the work area.

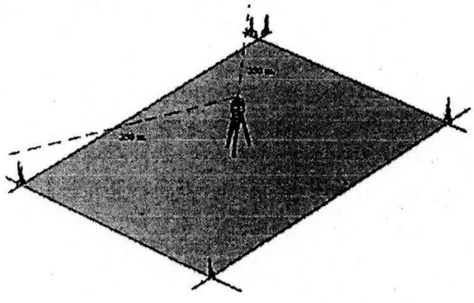

Fig. 5: Locating the emitter on sizeable pavements

In order to carry out the levelling for pavements on steep terrain, the optimum position for the emitter is such that the height of the laser will allow it to do the maximum amount of work possible before moving the device again. It is advisable to start off from the highest part, with the laser receivers for the machine in their lowest position, adjusting the height of the emitter so that the receivers will catch the laser beam. As the work is done lower and lower down on the embankment, the receivers can be raise to match the different height of each pavement. When the receivers reach their maximum height, they are adjusted down to the lowest position again, changing the position of the emitter towards the lowest part of the embankment, until the receivers laser can catch the beam again and the levelling work can begin again.

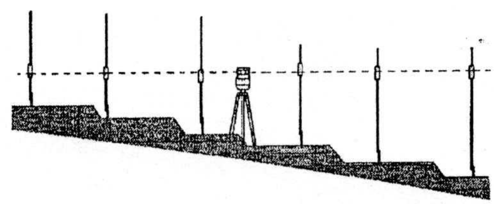

Fig. 6: Locating of the emitter on steep terrain

5. - OPERATIONS PRIOR TO LEVELLING WITH LASER GUIDANCE.

In order to carry out the levelling with the laser guidance method with good results a number of operations have to be performed which are described in the following paragraphs.

5.1. CALIBRATING THE LASER FIELD.

In order to check that the laser is in perfect condition and does not make any mistakes in the levelling it is necessary to carry out a check every day on the calibration for the emitter. This consists of checking that the plane for levelling that is selected on the emitter corresponds to what is really going to be levelled.

As follows the method for calibration is summed up. First the laser emitter is put into place, selecting the automatic mode for levelling and a slope of 0% is elected in both directions. The levelling-rod control is place at a distance "D" between 50 and 100 m. supporting it on firm ground, then the emitter is aligned with the levelling-rod and the detector is raised or lowered until the signal of "correct level" is obtained and it is locked into this position. Next the emitter has to be turned 180° so that the levelling rod may be targeted with the opposite side of the emitter. Next the emitter is raised or lowered to a distance "h" until the signal of "correct level" is obtained again, the error in calibrating the length between the emitter and the levelling-rod will be equal to half of the distance that the emitter has been moved ($e=(\Delta h/D)/2$). Then the emitter is raised or lowered to the middle position between the two previous ones and if the error detected is greater than the acceptable one, the system of calibration must be adjusted (it is usually an adjustment screw) until obtaining the signal for correct level again.

For the calibration of the second axis (perpendicular to the first one) the emitter is turned 90° and you check that the levelling-rod continues to show the signal of "correct level". Should this not be the case, it is adjusted using the corresponding system for calibration.

5.2. AXIAL ALIGNMENT OF THE LASER EMITTER.

The laser emitter must be aligned in parallel to the direction with the least slope on the pavement, for this purpose, two stakes shall be place on the pavement in parallel to the smaller the slope, then position the emitter directly over on of them and view from the levelling-rod for control that will located on the other stake. Next the height of the levelling-rod is changed until it gives the signal for "correct level", it is fixed into this position and finally the greatest slope is selected on the emitter (it will correspond to the direction perpendicular to the one that was sighted earlier). Once these operations have been carried out, the levelling-rod must continue to give out the signal for "correct level", if it does, the slopes defined in the project shall be selected and the emitter will be ready to start levelling.

5.3 FITTING AND ADJUSTING THE BLADE AND THE LASER RECEIVERS.

Once the emitter has been aligned and the desired the slopes have been selected on it, the next step is to adjust the receivers placed on the blade of the cutting tool.

In order to install them, a stake is put into place with the head at the elevation for the desired levelled space, the levelling-rod for control is placed on the stake and its height is changed until the signal for "correct level" is obtained, the gauged ruler is chosen so that it may be checked whether we have to cut or fill, based on the height that was taken on the reference stake. Next the blade is supported on the ground and is levelled to a short pass, once the pass has been completed it is checked with the levelling-rod whether it is cutting high, low or at the right elevation, then the laser receiver on the machine is raised or lowered in order to cut at the correct level.

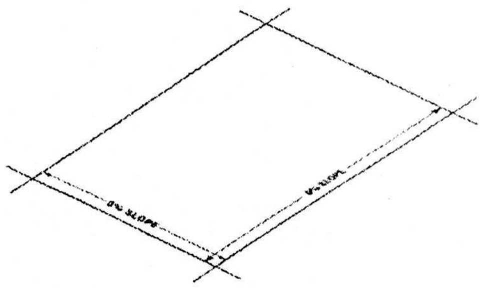

Fig. 7: close-up of the uniform cut with the motor grader and checking the elevation with the control levelling-rod.

6. - SOME APPLICATIONS FOR THE LASER-GUIDED SYSTEM.

6.1. EXECUTION OF HORIZONTAL PAVEMENTS.

When horizontal pavements are levelled, the laser does not have to be aligned in parallel to the axes for the levelled space. It is advisable to choose a position that will allow the calibration to be done easily, away from the path of the machines, and as has already been mentioned, as low as possible for greater stability, and for handling the emitter more easily.

6.2. EXECUTION OF SLOPING PAVEMENTS.

When sloping pavements are levelled, the emitter should be aligned in such a way that the slope selected will be parallel to the slope for the work area.

6.3 CROWN ON SURFACE AREAS.

Laser-guided control may be highly effective in projects for airports and motorways, providing that the longitudinal slope is constant, for a reasonable distance, and the cross-section of the surface is straight.

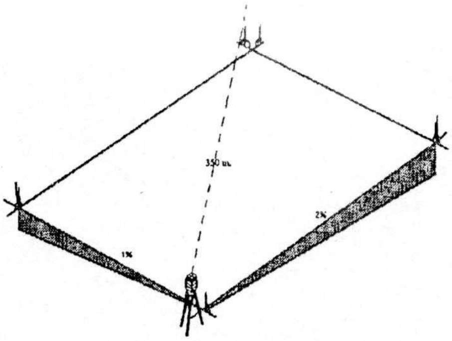

Fig. 8: Example of pavement with two slopes to be levelled with the laser system.

In the levelling and smoothing of a crown surface each side of it shall be considered to be a pavement with a different slope or a "plot with different levelling ". It is advisable to place the emitter on the lines that define the different planes that make up the surface and that shall be different zones for levelling. Thus both planes may be levelled without having to change the position of the emitter. The laser emitter must be adjusted in a different way for each one of the levelling zones.

On some sites it may be worthwhile using two laser emitters simultaneously for different sections of the work. In this case care must be taken to place them with a height difference of at least 30 cm in order to ensure that each machine only receives the signal from the emitter corresponding to its plot of work.

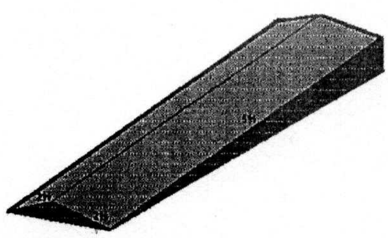

Fig. 9: Example of surface crown to be levelled by laser.

6.4. EXECUTION OF STEEP SLOPES.

With the laser guidance system the execution of steep slopes may be undertaken, which are typical of projects for dams, canals, etc. In these types of projects, checking and laying out with stakes takes up a great deal of time. Using laser control this time may be drastically reduced, thereby cutting labour costs and increasing the yields. As in the case of the earthworks, the receivers mounted on the machine provide the operator with a continuous reference of his position with respect to the surface to be achieved. As follows, an operating method with the laser guidance system is described for the execution of this type of work.

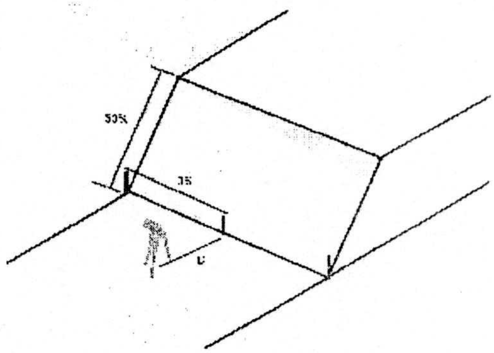

Fig. 10: Position for the emitter on steep slopes

In principle, two stakes are located on the line of transition between the slope and the horizontal pavement, or very close, parallel to the edge. Using the laser (selecting a slope of 0 %), the stakes are position on the same elevation (level zero).

The laser will be set up on the lower part of the slope, right behind one of the stakes, and perpendicular to the line of the two stakes, at an appropriate distance from the transition edge so that the receivers an catch the laser beam.

Next the desired slopes have to be selected on the emitter and the laser is aligned visually. Next, the gauged levelling-rod is fitted on to stake 1 (the nearest one), adjusting the sensor until the *"signal for correct level"* is obtained, and it is blocked into this position. The gauged levelling-rod is put into place without moving the sensor on stake 2, using the base for the horizontal alignment, and the laser is turned until the *"signal for the correct level"* is obtained.

The gauged levelling-rod is placed on stake 1 (without moving the sensor) and the *"signal for the correct level"* should be obtained again.

7. – DIGGING WITH LASER TECHNOLOGY.

In the execution of digging it is also possible to benefit from the advantages that the use of laser-guided equipment offers. In the case of digging works, a receiver mounted on the machine (generally a backhoe) receives the signal of reference from the emitter and sends it to a control box, that together with the information received by some sensors mounted on in the moving parts of the machine sends the corresponding signals to the hydraulic system for the machine so that it may dig totally automatically.

In this case the equipment consists of a laser emitter, a laser receiver, sensors for control, a control box for valves and a control panel. The laser emitter and the receiver make sure that the machine is located on the right elevation and in the right position, the control sensors measure the angles between the different parts of the machine informing the system about the position of the scoop, the control box for valves automatically works the hydraulic system for the backhoe and the control panel allows the operator to enter the data for the desired digging and to find the degree of advance for the work.

On the control panel the operator has a screen that allows the automatic control of the depth or slope of the cut in any work for digging.

The versatility of the system allows digging to be performed with a given slope, perform digs with a constant depth or the execution of trenches for which the floor is determined by a plane defined by the laser. This system also provides the possibility of performing "blind" digging, for example trenches under water, since it keep the operator informed at all times about the position of the scoop with respect to the final plane for the dig.

The applications mentioned above mean that this system is especially recommended for digging embankments with precise slopes, projects for pipelines and sewers in which a high degree of accuracy is required for the elevation of the dig, as well as for foundation works since it prevents excess digging, thus cutting down the surveying costs.

In large earthworks its use is less advisable since the materials are usually more consistent, which means that the manoeuvring of the machine is controlled by the hardness of the terrain and the activities performed do not require the same degree of accuracy as in the types of works mentioned in the last paragraph.

8. YIELDS AND COSTS IN EARTHWORKS WITH LASER GUIDANCE.

As follows the yields and costs are going to be analysed that are obtained in the levelling of a layer of crushed aggregate 25 cm thick and its subsequent compacting.

It should be pointed out that regardless of the guidance method, it is advisable to carry out a number of trial strips in which the optimum compacting operation may be found (optimum humidity for the material, number of passes, rate and width selected on the compacting machines, etc.), as well as the settlement of the layer after the compacting work.

The first operation that is carried out is the unloading of the artificial aggregate in well spread piles in the zone to be levelled. Next the *spreading* of the piles if carried out (the laser is not used for this operation) until the upper level of the layer is located at about 5-7 cm above its final elevation, next we start to use the laser system and the *levelling* is done for the layer at an elevation above the final one that is equal to the settlement obtained in the trial strip. At this time we continue to carry out the prior compacting of the layer with a vibrating compactor. After having carried out this prior compacting work , we go on to perform the *smoothing* of the layer with the laser system, and then on to its final elevation. To finish off, the layer is compacted with a vibrating compactor until the required density is achieved.

So far it has been seen that three main operations are required:

- *Spreading* of the material.
- *Levelling* of the layer.
- *Smoothing* of the layer.

Below, the different units of equipment needed to perform the levelling are described of the features mentioned earlier, with the traditional method using stakes, with the one with ultrasonic and with laser guidance:

- Equipment and staff for levelling with the stake method:
    - Motor grader for 205 kW and weighing 27.2 Metric tons
    - Water tanker for 10 m3
    - Vibrating compactor weighing 19 Metric tons.
    - 2 Foremen
    - 5 Labourers
- Equipment and staff for levelling with ultrasonic method:
    - Motor grader for 205 kW and weighing 27.2 Metric tons
    - Water tanker for 10 m3

- Vibrating compactor weighing 19 Metric tons
  - 1 Foreman
  - 3 Labourers
- Team for levelling with the laser method:
  - Motor grader for 205 kW and weighing 27.2 Metric tons
  - Water tanker of 10 m3
  - Vibrating compactor weighing 19 Metric tons
  - 1 Labourer

The following chart includes the different yields obtained in each one of the operations for the different methods of levelling:

The yields of the different equipment and staff for the operations of spreading and levelling were estimated to be similar in all three cases though the yield for levelling with the laser system is around 30% higher since the high speeds of the motor grader do not affect the laser equipment.

As far as yields are concerned, there are significant differences between the "automated" methods and the manual one with stakes, with yields having been observed of around double with respect to the traditional method.

The yield of the levelling for the laser system is around 20% higher than that achieved by the ultrasonic method, with this difference mainly involving the reduction in the time spent on the smoothing through a higher working speed of the motor grader and the reduction of the time spent on the levelling, for the same reason as before.

As far as costs are concerned, some approximate costs have been assumed, both for the machinery and for the labour.

As far as purchase price is concerned for ultrasonic and laser equipment, the former consists of two sensors, one for the slope and other for rotation, two ultrasonic emitters, a valve box and a longitudinal sensor and a control box, with the price standing at Pts 3,019,700.
The laser system consists of two laser receivers, one emitter, a control box, a box of connections and a box of valves with the price for all of this standing at Pts. 5,168,200.

At the present research is being carried out in order to be able to make these devices commercially competitive so that they will overcome the main drawback of the laser as compared to the ultrasonic method which lies in the fact that it allows warped surfaces to be obtained. The advances in this sense are set out in detail in the following section.

9. - LATEST ADVANCES IN LASER TECHNIQUES.

At the present time, different modifications to the laser equipment are being prepared, aimed at greater effectiveness and ease of use with the resulting increase in production. Some of these mean improvements to the system described in this report, amongst which we may mention the handling of the controls of the emitter by remote control thus managing to do without the use of ladders, avoiding accidental movements of the tripod through knocks, etc. another modification is the self-alignment for the device with the desired directions.

Another advance has been the incorporation of the laser into a total station in which the project data are stored, informing the operator of the machine about its position and the deviation with respect to the elevation of the levelled area. With this new method it will be possible to perform the levelling for any three dimensional surface.

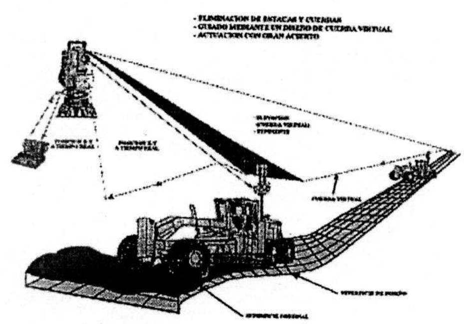

Fig. 11: laser system coupled to a robotic total station

10. - OTHER MODERN GUIDANCE SYSTEMS.

There are other systems for guiding machinery of which the GPS and the electromechanical optic systems are the most outstanding one. The systems based on the GPS (Global Positioning System) applied to construction and civil engineering techniques use two types of technologies: real time kinematic (RTK) and in movement (OTF) thus obtaining pinpoint levels of accuracy both in the stationary position and in movement, these technologies are backed by reference stations located in a position determined and known topographically. The use of this technology in levelling work will allow the elimination of the use of stakes and their replacement by two-way computerised systems between the operator of the machine and the project data.

The electromechanical optic systems assign a virtual direction for guidance using an optical system with prisms which are mounted on the machinery and a total robotic station in which the project data are stored, this total station provides information in real time for the machinery using a laser beam. There are other systems in which this type of communication is achieved using radio The advantage of this system is that it allows the execution of any type of surface, as well as having information available at all times on the state of the work in real time. In the case of using radio waves the drawbacks may lie in the alteration of the radio waves sent by the station through interference from different sources. These sources of interference may be sizeable in works in urban areas, close to radars, repeaters, etc. Another drawback of this method is that it is around 5 or 6 times slower than the laser system.

11. - THE FUTURE: TOTAL AUTOMATION

The control and guidance of machinery is being implemented in a process with a sequence in three phases:

Guiding of machines for the operators.- The **GPS** technology currently offers the guidance of machines and backing for the operators, providing precise information about the existing systems, in real time, referring to the position of their equipment.

Guidance by remote control.- It is the next phase in **GPS** guidance and control of machinery, for example, lorries, diggers and loaders, which may be of great use for those sites that are known to be unsuitable, unsafe or uncomfortable for the operator.

Total control of machines.- This is the final phase of the process, and may be said that it is now in its infancy. Using the **GPS** guidance and control of machinery, in a not too distant future, we may be able to send the information on the plans directly to the machines, and these will take charge directly of their execution with great accuracy, substantially cutting down costs, errors, repetition of work and surveying, and affording a noticeable increase in safety.

In order to convert this into reality, the **GPS** systems would have to be coupled with other technologies, such as the systems of hydraulic control, the detection of obstructions by ultrasonics or laser, or recognition by video picture. This system, already used in the last few years in surveying or oil prospecting, must mean for building and civil engineering a true revolution in information systems, allowing them to have a tool with enormous potential for the supervision and information about the works.