Project on Geospatial Information for Sustainable Land Development in Tirana - Durres Area

Levelling

Manual (v.1)

MAY 2020

JICA Project Team

TABLE OF CONTENTS

1. Introduction

Levelling is the survey to determine the elevation of new points based on known points by measuring differences in height by using a level and levelling staffs.

1.1. Class of Levelling

This manual describes about the 1st order leveling surveys. The type of known bench marks and the distance between known bench marks are as follows.

Class of levelling	Known bench mark	Distance between known bench mark
1st order	1st order	Less than 400km

1.2. Levelling route and network

First order levelling route is composed of more than 2 known bench marks.

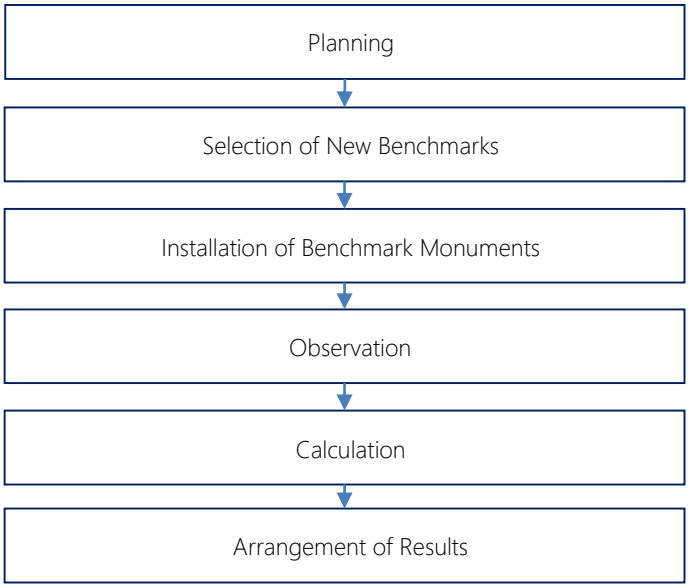
Levelling network refer to a network composed of more than two levelling circuit in a net-like form.

1.3. Method of Levelling

The levelling will be undertaken using Direct Levelling as standard.

1.4. Workflow

The leveling survey work is performed according to the following workflow.



2. Work manual

2.1. Planning

(1) Summary

i. An appropriate plan including the method of work, main equipment, workforce and schedule will be formed before starting work.

ii. Existing benchmarks will be confirmed based on a topographic map. The approximate position of new benchmarks and the levelling routes will be decided and the work plan sheet will be prepared considering the following.

a) The scale of topographic map to prepare the work plan sheet will be selected based on the order of levelling and the targeted area of new benchmarks to be established.

b) The new benchmarks will be selected by equal distance considering the interval of new benchmarks on the levelling routes in principal.

(2) The work plan sheet

The following items shall be described in the work plan sheet created in the planning stage.

i. Existing benchmarks

ii. Approximate position of new benchmarks

iii. levelling routes

2.2. Selection of New Benchmarks

(1) Summary

"Selection of New Benchmarks" means the work to study the present state of the existing benchmarks and levelling routes and to select the position of new benchmarks in the field based on the work plan sheet and to prepare the selected point sheets and work sheets.

In point selection operation, it is important following issues.

a) Accessibility
b) Firm ground
c) Preservation

(2) Reconnaissance of Existing Benchmarks

In the reconnaissance of existing benchmarks, the existing benchmarks will be studied to confirm whether there are any abnormalities. And the results of reconnaissance will be described on the selected point sheet.

(3) Selection of New Benchmarks

The new benchmarks will be selected properly considering its utilization in the subsequent works.

(4) Preparation of Selected Point Sheets and Work Sheets

i. The position of new benchmarks and the levelling routes will be expressed on the topographic map when the positions of new benchmarks are selected, and a selected point sheet for each selected benchmark location will be prepared.
ii. The work sheet will be prepared based on the selected point sheet.

2.3. Installation of Benchmark

(1) Summary

"Installation of Benchmark" means the work to establish a permanent monument at a new benchmark.

(2) Installation of Benchmarks

The installed permanent monument will be recorded with photographs.

(3) Preparation of Point Description

The point description will be prepared for all installed new benchmarks.

2.4. Observation

(1) Summary

"Observation" means the work to observe the height difference between relative points using levelling instruments and staffs, etc. based on the work sheet.

(2) Equipment for Observation

i. The equipment for observation will be the standard equipment listed in the following tables.

ii. Electronic Level

Class of Level	1stOrder
Shortest length of sight(m)	3.0m or less
Minimum Scale Value (mm unit)	0.01 mm
Reading Method	With auto reading system by electronic images processing method
Auto Correction System, Official Sensitivity	0.4 or less
Circular Bubble Tube, Official Sensitivity	8 or less
Remarks	Coincidence Bubble tube, and with a fine adjustment system for a collimation line.
Category of Levelling	1st order levelling

iii. Levelling Staff

Staff Class	Scale			Entire Length	Sensitivity of attached Bubble Tube	Figure	Category of Levelling
	Material	Scale	Scale Accuracy				
1st Order	Invar	Scale interval of 10mm or 5mm, Both side scale or bar-code scale	50μm/m or less	3m	15 ~ 25 or less	Linear	1st order levelling
			51μm/m ~ 100μm/m	3m or less	15 ~25 or less	Linear	1st order levelling

iv. In the first order levelling, first order levelling staff that has a correction value of less than 50μm/m

at 20 degrees and the difference of correction value of I staff and II staff is less than 30μm/m will be used.

(3) Inspection and adjustment of equipment

i. The equipment to be used in the observation will be inspected and calibrated on a timely basis. In addition, in case of inspection and calibration of collimation line error by observation, the reading unit and acceptable range will be following the classification standards as described in the table below.

Category / Item	First Order
Reading Unit	0.01 mm
Acceptable Range	0.3 mm

ii. The inspection and calibration will be carried out according to the following items and the results will be recorded on observation sheets and will be conducted about every 10 days during the observation period.

a) In case of electronic levels, the circle water level and the collimation line will be inspected and calibrated, and together the compensator will be inspected.

b) The water level attached to the staff will be inspected.

(4) Implementation of Observation

i. The observation will be carried out according to the following defined items based on the work sheet.

ii. Direct Levelling

a) In the observation, the scale marks and the distance between the level and the foresight or back sight staff (hereafter "collimation distance") will be observed.

Note: The reading unit of collimation distance and scale marks will be the following classification standards as described in the table below. In addition, the collimation distance will be observed in meter units.

Category / Item	First Order Levelling
Collimation Distance	Maximum 40 m
Reading Unit	0.1 mm

Note: The observation will be one collimation to one reading and the reading method of staff will be as per the classification standards described in the table below.

Category / Order of Observation	First Order Levelling
	Electronic level

1	Back sight
2	Foresight
3	Foresight
4	Back sight

b) The observation will be two-way observations.

c) The staffs to be used will be two staffs as one set and the staffs will be swapped over on the return observation.

d) In the first order basic levelling, the temperature will be measured at one degree units at the starting time, ending time and on arrival at every fixed point.

e) The collimation distance will be same distance and the level will be set up on the line connecting both staffs wherever possible.

f) In case of the levelling of two-way observation, if there are a lot of survey points, the fixed points will be established arbitrarily and these fixed points will be used commonly on the outward and return of the observation.

g) In the first order basic levelling, the lower part of staff such as less than 20 cm will not be observed.

h) The daily observation will be ended at benchmarks in principal. In addition, if the levelling stops at a fixed point by necessity, the fixed point will be inspected to ascertain whether there are any abnormalities before restarting the observation.

i) The observation points are even number.

j) When conducting observation at newly benchmark, wait more than 24 hours after installation benchmark.

(5) Important points of Digital Level Observation

i. Before starting observation, keep the instrument in observation environment for necessary time (about 20 minutes) to fit the outside temperature for matching the observation environment.

ii. A level and staff should be placed where there is no obstacles the view. When the obstacles occupy accounts 30% in the view with leaves or wire netting, it will be a measure value including the error or an error.

iii. The contrast settings of the staffs should be same. When there is light or shade, the whole view of the staffs should be sheltered by sunshade. When there is light or shade in the staff in the view by buildings and trees, it will be a measure value including the error or an error.

iv. Avoid placing the staffs where the background is with any kind of strong in catoptric light, a plastic greenhouse, the surface of the sea or lake, a road guidance board and a car, etc. The view back is sheltered for a sunshade. It will be a measure value including the error or an error.

Obstacle in the view

Light and shade on the staff

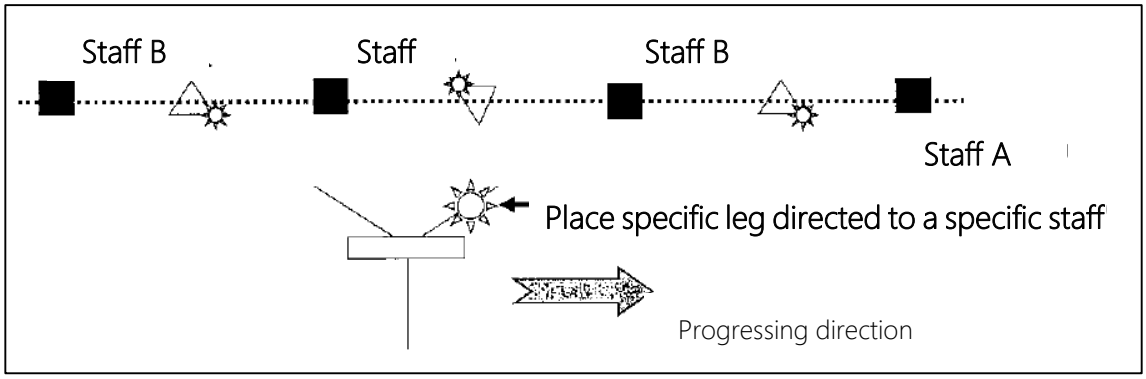
(6) Types of errors and elimination process

i. Level errors and elimination process

Concerning with the Level		
Error		Elimination & Minimization method
Collimation line	Inclination of Collimation line	Back & fore sight distance from the level must be same
Vertical axis	Tilting the vertical axis in a fixed direction	Tripod's specific foot alternate left & right respect to the observation direction
Compensator features	Vertical inclination of the compensator	Set circular bubbles to the center completely, and level the telescope always to the same staff
Hysteresis	Compensator not returning to the vertical direction	Face the telescope to the same staff precisely from the upward state
Tripod settlement	Uniform sinking of the tripod over time	Observation order is back -> fore -> fore -> back

ii. Vertical axis error

By setting two legs of the tripod parallel to observing direction and placing a specific one leg always facing the same staff, errors can be reduced.



The error can be eliminated by setting the number of stations to an even number on a straight and flat line.

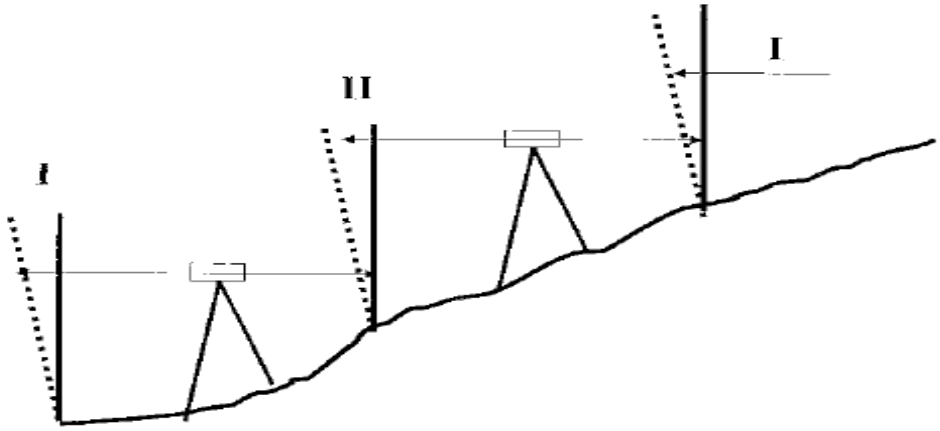
iii. Staff errors and elimination process

Concerning the staff		
Error		Elimination & Minimization method
Zero scale	Which the bottom of the staff and	The error can be eliminated by setting the

	the zero scale does not coincide	number of stations to an even number
Graduation	Incorrect interval of the staff barcode and error due to material expansion or contraction a cause of temperature	Implement a constant inspection of the graduation. Use a precise graduated staff. Swap the staffs when go & back observation
Inclination	Deviation of circular bubble tube attached to staff	Adjust the circular bubble in the center of the tube when the staff is vertically set
Sinking	Sinking of the staff turtle over time	Place the turtle on a solid ground, and step on it firmly. Observe in the order of back -> fore -> fore -> back

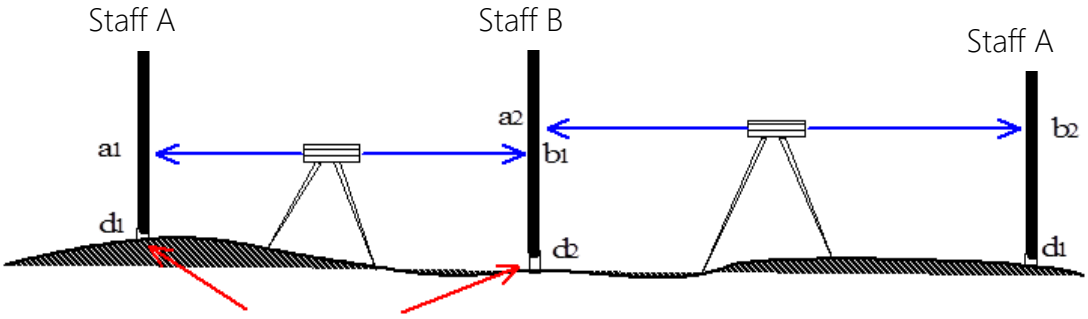
iv. Error due to circular bubble tube of the staff

If the circular bubble tube is unadjusted, the inclination of the lower staff will always be larger than upper staff on the sloped land. This is a cause of large error.



It is possible to reduce the error by setting the number of observation points to even number and by using different staffs (I, II) at the starting point during round-trip (go and back) observation.

v. Zero scale error of staffs



$$\{ (a1+d1) - (b1+d2) \} + \{ (a2+d2) - (b2+d1) \}$$

$$(a1-b1) + (a2-b2) \qquad = (a1 - b1) + (a2 - b2)$$

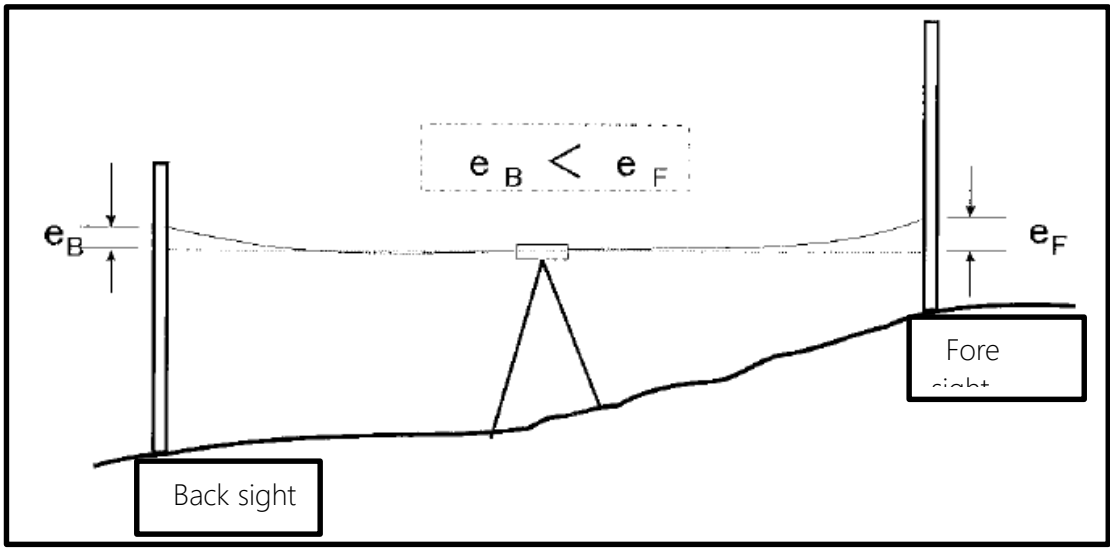
vi. Natural phenomena error and elimination process

Error		Elimination & Minimization method
Spherical	Caused by the curvature of the earth	Back & fore sight distance from the level must be same

Error		Elimination & Minimization method
Atmospheric	Change of the atmospheric refraction	Back & fore sight distance from the level must be same. Do not read below 20cm of the staff. Reduce observation distance.
Flame	Large flutter due to flame	Reduce observation distance, or stop observation
Sunshine	Expansion of the circular bubble tube and the influence on the electronic parts caused be the direct rays from the sun	Avoid direct rays by using parasol
Change of atmospheric difference	Weather changing in short period	Reduce observation distance. Implement observations separately, going in the AM and backing in the PM.

vii. Error due to atmospheric refraction

The refraction of the atmosphere depends on the temperature of the optical path, and the optical path (sighting line) passing near the surface of the earth reads the staff graduation largely.



Note: In a certain sloping ground, it is an error to reduce the height difference.

viii. Staff correction calculation (staff correction)

Correct stretching of staff due to temperature

Regarding the 1st order levelling, correct it for all observation height. (staff correction)

Staff correction amount: Calculation using staff revision number at temperature of 20 degrees (reference temperature)

Staff correction amount (m unit) : $\Delta C = [\, C0 + (T - T0)\, \alpha]\ \Delta H$

C0 : Staff constant at reference temperature T 0 (Correction amount in 1 m unit)

T : Measured temperature at observation (℃)

T0 : Reference temperature (℃)

α: Expansion coefficient

ΔH : Observation height difference (m)

≪Calculation example≫

Staff constant C0: +3μm/ m
Measured temperature at observation T : 25℃
Expansion coefficient α: 1.0×10^{-6}m/℃
Observation height difference ⊿H : −50.8562m

Staff correction amount : $\Delta C = [\,C0 + (T-T0)\,\alpha]\,\Delta H$

$= [+3\times10^{-6} + (25-20)\times1.0\times10^{-6}]\times(-50.8562m)$

$= [+8\times10^{-6}]\times(-50.8562m) = -0.0004m$

The height difference after correction is

ix. Orthmetric height collection

Formula

$$\Delta G=[\{(g_P + g_Q)/2\}-\gamma_0]\times\Delta h/\gamma_0+H_P\times(Gp-\gamma_0)/\gamma_0-H_Q\times(G_Q-\gamma_0)/\gamma_0$$

ΔG ： Orthometric correction (unit：mm)

g_P , g_Q：Gravity of the benchmarks P and Q (unit：mGal)

Δh ：Height difference between points P and Q (unit：m)

γ_0 ：Normal gravity of latitude 45 degrees (unit：mGal)

GRS80 ： 980619.92mGal

H_P , H_Q ：Orthometric height of the benchmarks P and Q (unit：m)

G_P, G_Q ：Average value of the vertical gravity of the benchmarks P and Q (unit：mGal)

$G_P = g_P + 0.0424H_P$

$G_Q = g_Q + 0.0424H_Q$

≪Calculation example≫

	B.M 1	B.M 2
Latitude (Degree Unit)	36.338	36.335
Longitude (Degree Unit)	138.567	138.545
Height (m)	977.36	979.47

Surface Gravity (mGal)	979,620.81	979,619.76
Average area value of the vertical gravity (mGal)	979,662.25	979661.29
γ_0	980,619.92	
$\{(g_1 + g_2)\times 1/2-\gamma_0\}\times \Delta h/\gamma_0$	-0.82	
$H_1 (G_1 - \gamma_0) / \gamma_0$	-336.84	
$-H_2 (G_2 - \gamma_0) / \gamma_0$	+338.53	
Orthometric correction	0.9mm	

2.5. Calculation

(1) Summary

"Calculation" means the work to determine the heights of new benchmarks based on the results of observation. The calculation will be carried out according to the following defined items.

i. In the first order levelling, the calculation of correction of staffs and the calculation of orthometric height correction will be carried out.

ii. The calculation of the first order levelling will be calculated to 0.1 mm (one decimal place).

(2) Method of Calculation

Various corrected calculations of the observed difference in height will be carried out using other calculation formulas defined differently.

(3) Inspected Calculations and Re-Observations

i. The inspected calculation will be carried out after the observation. However, in case of exceeding the acceptable range, the appropriate measures such as re-observation will be applied.

a) For all levelling unit loop (levelling loop formed by new levelling routes and those without levelling routes within them) and all inspected routes that are selected under the following conditions, the closure error of loop and between existing benchmarks will be calculated and the quality of the observation will be inspected.

Note1: The inspected routes will be formed by connecting the existing benchmarks.

Note2: All existing benchmarks will be connected by more than one inspected route.

Note3: For all levelling unit loops, the part of its loop will be overlapped by the inspected routes.

b) The acceptable range of the inspected calculation will be as per the classification standards described in the table below.

Category	1st Order Levelling

Item	
Closure difference of loop	2 mm√S
Closure difference between existing benchmarks	15 mm√S
Remarks	S：Observation distance (One way：km unit)

ii. The results of inspected calculations will be arranged in the accuracy control table.

(4) Adjustment

i. The adjustment will be carried out according to the following defined items.
   a) The adjustment of direct levelling will be carried out using an observation equation or a condition equation whereby the weight is the inverse of distance.
   b) The adjustment of combined direct levelling and river-crossing levelling will be carried out using an observation equation or a condition equation whereby the weight is the inverse of the squared standard deviations.
   c) The acceptable range of the adjustment will be as per the following classification standards described in the table below.

Item \ Category	1st Order Levelling
Standards deviation of observation per unit Weight	2 mm

ii. The software of the adjustment will be confirmed that the results of adjustment are corrected.

iii. The results of adjustment will be arranged in the accuracy control table.

2.6. Arrangement of Results

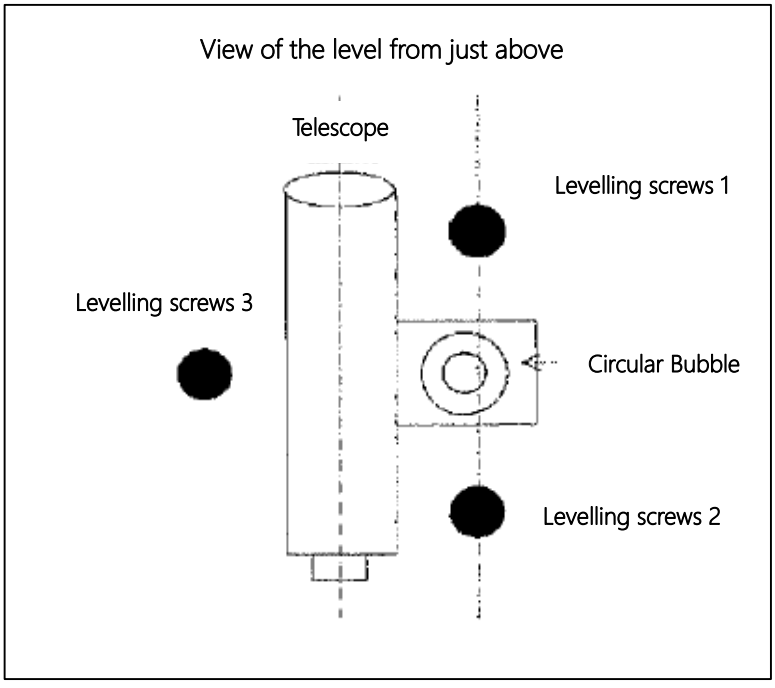
The results will be as follows. However, the results will depend on the method of levelling.

a) Observed field notebook
b) Results of observation and of adjustment
c) Route of levelling
d) Calculation book
e) Adjustment sheet
f) Point description
g) Digital data of results
h) Photographs of survey markers
i) Accuracy control table
j) Inspected survey book

3. Sokkia SDL1X Digital Level Inspection and Adjustment

3.1. Inspection and adjustment of the circular bubble

1) Adjust the levelling foot screws until the bubble is centered in the circle.
2) Turn the instrument 180°. The bubble should not shift from the center. If the bubble does move, adjust as follows.
3) Compensate for one-of the shift by adjusting the levelling foot screws.
4) Eliminate the remaining shift by turning the circular level adjusting screws with the hexagonal wrench until the bubble is center.
5) Turn the instrument 180°. If the bubble stays in the center, adjust is complete. If the bubble moves, repeat step 3) and 4).
6) Turn the instrument 90 °. The bubble should not shift from the center. If the bubble does move, adjust as follows.
7) Compensate for one-of the shift by adjusting the levelling foot screws.
8) Eliminate the remaining shift by turning the circular level adjusting screws with the hexagonal wrench until the bubble is center.
9) Turn the instrument 180°. If the bubble stays in the center, adjust is complete. If the bubble moves, repeat step 7) and 8).

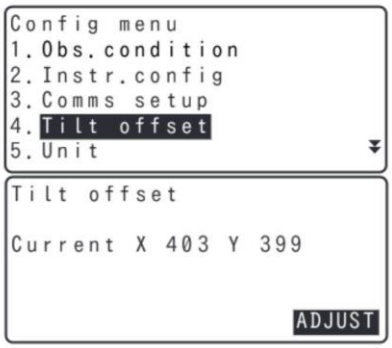


3.2. Tilt Sensor

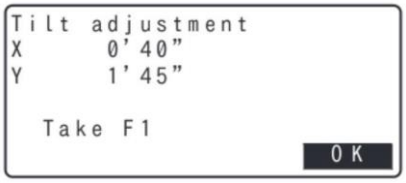
If the tilt sensor shifts from angle 0°(zero point), the instrument is not correct leveled. The actual circular level and graphic level will not be displayed correctly. Perform the following procedure to cancel the tilt zero point error.

PROCEDURE Checking and adjusting

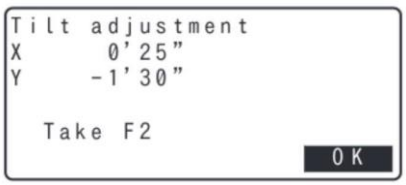
1) Carefully level the SDL. If necessary, repeat the procedures to check and adjust the circular level.
2) Select "Config" in <Menu>.
3) Select "Tilt offset" in <Config menu> to display the current correction constant in the X(sighting) direction and Y (horizontal axis) direction
4) Press [ADJUST] to display the tilt angle in the X (sighting) direction and Y (horizontal axis) direction.



5) Wait a few seconds for the display to stabilize, then read the automatically compensated F1 angles (X1 and Y1).



6) Press [OK] and rotate the top of the instrument and 180°while referring to the horizontal circle.



7) Wait a few seconds for the screen to stabilize, then read the automatically compensated F2 angle (X2 and Y2).
8) In this state the following offset values (tilt zero point error) are calculated.
   X offset = (X1 + X2)/2
   Y offset = (Y1 + Y2)/2

If one of the values (Xoffset, Yoffset) exceeds ±1′ , adjust the value using the following procedure. When the offset value falls within the rage ±1′ , Press [ESC] to return to <config menu>.

9) Press [OK] and rotate the top of the instrument and 180°while referring to the horizontal circle.

10) If the new correction constants are within the range 400±50, press [YES] or [ ] to renew the correction angle. <Config menu> is restored.
If the values exceed the adjustment range, select [NO] to cancel the adjustment and restore <Tilt offset>.

Contact local dealer to perform the adjustment.

PROCEDURE Recheck

1) Select "Tilt offset" in <Config menu>.
2) Wait a few second for the display to stabilize, then read the automatically compensated F3 angles (X3 and Y3).
3) Press [OK] and rotate the top of the instrument and 180° while referring to the horizontal circle.
4) Wait a few seconds for the display to stabilize, then read the automatically compensated F4 angles (X4 and Y4).
5) In this state the following offset values (tilt zero points error) are calculated.
X offset = (X3 + X4)/2
Y offset = (Y3 + Y4)/2

When both offset values fall within the range ±1′ , adjustment is complete. Press [ESC] to return to <Config menu>.

If one of the offset values (X offset, Y offset) exceed ±1′ , repeat the check and adjustment procedures from the beginning. If the difference continues to exceed ±1′ after repeat the check 2 or 3 times, have your local dealer perform the adjustment.

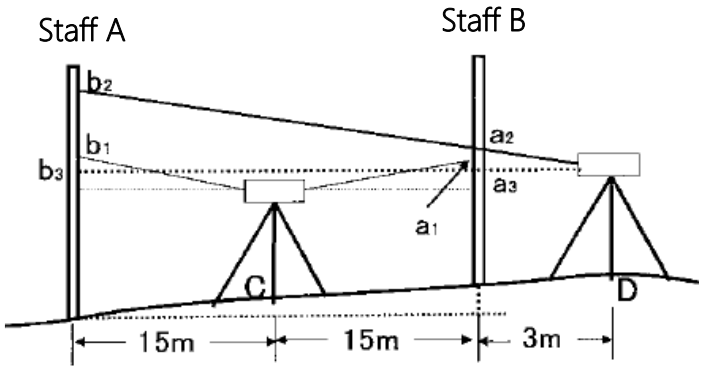
3.3. Inspection and Adjustment of the Collimation Line

Adapt to the outside temperature, expose the level to the outside for about 20 minutes

Detects the inclination amount (collimation line correction angle) of the collimation line by the unequal distance method

Stores the collimation line correction angle to the level

Confirm whether the value corrected of the collimation line correction angle by the unequal distance method does not exceed the following allowable range (tolerance)



Class / Level	Reading unit	Tolerance
1st order	0.01mm	0.3mm

3.4. Adjusting the Reticle

The reticle cross-lines can be corrected if out of adjustment. While reading the staff RAB-code, adjust the reticle by correcting the reference value of the CCD line sensor and then make mechanical adjustments to the instrument.

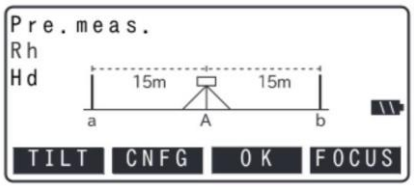
As described in the following procedure, high accuracy readings are obtained bay taking repeat readings of the staff.

PROCEDURE Correcting the reference value of the CCD line sensor

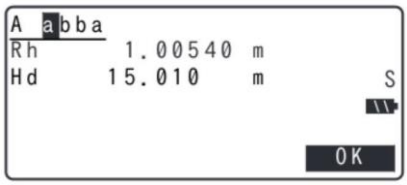
1) Select "Means" in <Menu>.

2) Select "Check & adjust".

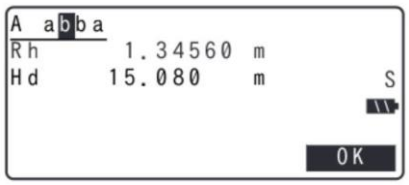
3) Place staffs a and b approximately 30m apart and set the instrument halfway between the staffs (position A).
4) Perform pre-measurement of staffs and a and b to check they are both approximately 15m from the instrument. Press [OK] to confirm.



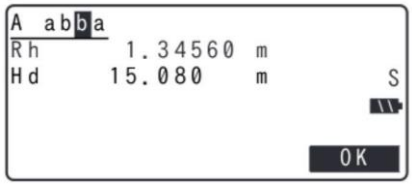
5) Measure staff a. Measurement results are displayed.



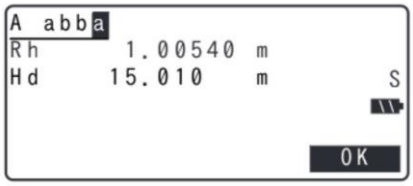
6) Press [OK] to accept the results.
7) Measure staff b.



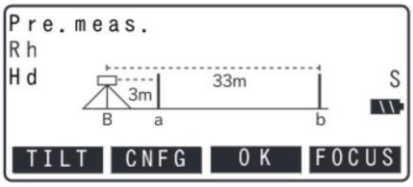
8) Press [OK] to accept the results.



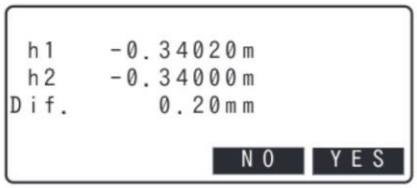
9) Measure staff b.
10) Press [OK].
11) Measure staff a.



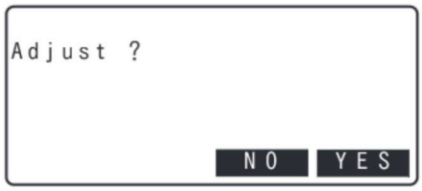
12) Press [OK] to accept the results.
13) Move the instrument to a position approximately 3m from the staff a along a straight line joining staffs a and b. The new position is B.
14) Perform pre-measurement of Staffs a and b to check that a is approximately 3m from the instrument and b is approximately 33m from the instrument. Press [OK] to confirm.



15) Repeat steps (5) to (12), sighting the two staffs and taking the readings.
16) Check the difference between the results and decide whether correcting the reference value of the sensor is required. If the difference is 0.3mm or less, no adjustment is necessary. If the difference is over 0.3mm, adjustment is necessary.



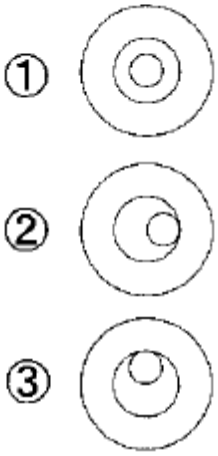
17) When adjustment is necessary, press [YES]. Press [NO] if no adjustment is necessary.
18) Press [YES] in the confirmation dialog shown at below.



19) The instrument calculates and records the required reticle adjustment from the measurement results, and then return to the menu selection.
20) Repeat steps (3) through (18). Make sure that the difference between the results is 0.3mm or less.

3.5. Function check of compensator (digital level)

Observe the following figure in the following order to obtain the height difference

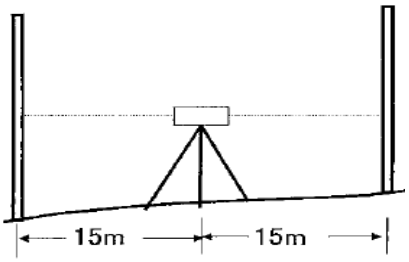


(1) Observe with the circular bubble manually set in the center

(2) Observe with the circular bubble manually set in the sight line

(3) Observe with the circular bubble manually set in the direction perpendicular to the sight line

(4) Check that the difference between (1) and (2), the difference between (1) and (3) is within 0.3 mm (standard of the function of the

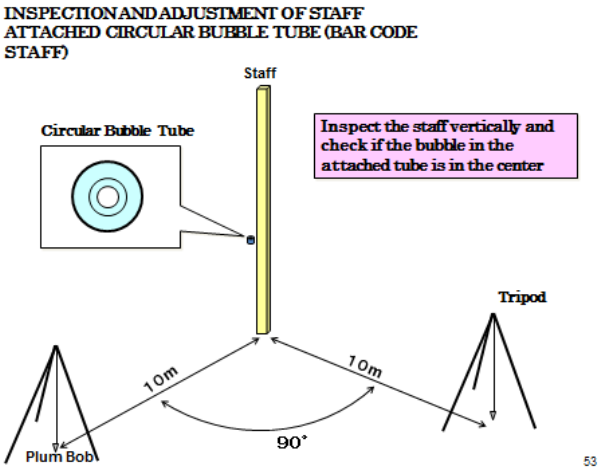


3.6. Inspection and adjustment of staff attached circular bubble tube (bar code staff)

Visual check of the staff and hanged thread from the front and side

Inspect the staff vertically and check if the bubble in the attached tube is in the center

If it is not in the center, adjust it to the center with adjustment screws



end