Box Culvert Design — User Manual

Nov 3, 2026 · BESPA Expert Systems

This manual covers **Box Culvert Design version 1.0.10** at **box-culvert.bespa.online**.

1. About the app

Box Culvert Design produces a checked reinforced-concrete box culvert in about 15 seconds. It gives you drawings, a DXF, a calculation report and a take-off billed in the Road BOQ Estimator's own item codes.

It designs single- and multi-cell boxes written as **n/BxH**: n cells, each B m wide and H m high (for example 2/3x3). Each design covers:

- **The barrel:** top and bottom slabs, exterior and interior walls, and inner-corner haunches, to AASHTO LRFD Bridge Design Specifications, 9th Edition, Section 12.11.
- **The end structures:** two headwalls, four L-shaped wingwalls, and an apron at each end with its toe wall.
- **Flotation:** a hold-down where the empty box would float with the water table at road level.
- **Outlet scour:** the outlet velocity and scour hole by FHWA HEC-14 (2006). Where protection is needed, the outlet is protected by loose rock (HEC-14) or a gabion mattress (FHWA HEC-23 Vol. 2, Design Guideline 10), whichever you choose or whichever is cheaper.
- **Quantities:** measured by the estimator's own box module, so a box designed here and priced in the estimator lands on the same bill lines.

Every design passes through an **audit gate** of independent checks. Until every check passes, each sheet and file is stamped **PRELIMINARY**. A design that passes is marked **AUDIT CLEAN - FOR THE ENGINEER'S CHECK AND SEAL**. The app does not replace the engineer: a licensed engineer must check and seal every design before it is used for construction.

2. Getting started

Open **box-culvert.bespa.online** and sign in with your Bespa licence. The app comes with your subscription.

1. If you are not signed in, the app takes you to the Bespa sign-in page. Enter the licence key from the email that issued your licence. You come back to the app once the key is accepted.

2. The page shows one form, **Design inputs**. Every field already holds a working default. Under each field are the lowest and highest values it accepts.
3. Fill in the fields (section 3) and press **Design**. A design takes about 15 seconds.
4. The results appear on the same page, above the form: the audit status, the bill, and links to download each output (section 4). The form stays filled in, so you can change a value and design again.

Things to know:

- **One design at a time.** Designs run one after another. If someone else's design is running, yours starts when it finishes.
- **Download within 24 hours.** Output files are kept for 24 hours and then deleted. Use **All (ZIP)** to take everything at once.
- **Sign-in problems.** If your key is refused, check that your subscription is active. A key whose subscription period has ended is not accepted. Never send your licence key by email or chat to anyone, Bespa support included.

3. Entering a design

Only the number of cells, the span and the height are essential. Every other field has a default that suits a typical low-volume road crossing.

The app never adjusts a value to fit its range. If any value is outside its range or is not a number, the form comes back with a message naming each bad field, and nothing is designed.

The box

Field	What it is	Default	Range
Number of cells (n)	Cells side by side	2	1 to 4, whole number
Clear span B	Inside width of each cell	3.0 m	1.0 to 6.0 m
Clear height H	Inside height	3.0 m	1.0 to 5.0 m
Barrel length L	Length along the culvert	10.0 m	2.0 to 80.0 m
Fill over the top slab Hcov	Depth of fill above the box	0.6 m	0.6 to 10.0 m
Member thickness t	Slab and wall thickness; 0 lets the app choose	0	0, or 0.20 to 0.8 m

Field	What it is	Default	Range
Haunch leg	Leg of the 45° inner-corner haunch	0.15 m	0 to 0.3 m
Reinforcement yield fy	Steel grade	420 MPa	420 to 500 MPa
Cover	Cover to the reinforcement	50 mm	50 to 75 mm
Unit weight of fill	Fill over and beside the box	19 kN/m³	16 to 22 kN/m³
Ko	At-rest earth pressure coefficient	0.5	0.3 to 1.0
Saturated unit weight of fill	Used for flotation (section 7)	20 kN/m³	17 to 23 kN/m³
Allowable bearing pressure qa	Of the founding soil	175 kPa	50 to 600 kPa
Apron length	Concrete apron at each end	1.5 m	0.5 to 3.0 m
Headwall height	Above the top slab	0.6 m	0.3 to 1.2 m
Wingwall divergence	Angle of the wingwalls	45°	0 to 60°

Concrete is fixed at **grade C30** (cube strength 30 N/mm²). The checks use the matching cylinder strength, f′c = 25 MPa. It is not a field on the form.

The outlet and its scour

Field	What it is	Default	Range
Culvert slope So	Sets the design flow	0.5 %	0.1 to 10 %
Manning's n of the barrel	Roughness of the barrel	0.013	0.011 to 0.020
Tailwater depth TW	Lowest expected depth at the outlet	0 m	0 to 10 m
Allowable velocity	Highest velocity the outlet channel can take unprotected	2.0 m/s	0.5 to 6.0 m/s
Outlet bed material	Cohesionless (sand, gravel) or cohesive (clay)	cohesionless	choice
Bed grading σ	(D84/D16)^0.5; cohesionless beds only	1.87	1.0 to 4.0

Field	What it is	Default	Range
Plasticity index PI	Cohesive beds only	12	5 to 16
Saturated shear strength Sv	Cohesive beds only	24,000 N/m²	1,000 to 200,000 N/m²
Peak flow duration	How long the peak lasts	30 min	30 to 1,440 min
Filter layer	Crushed stone under the rock or mattress	0.15 m	0.10 to 0.50 m

The design flow is the barrel's **full-bore capacity**, worked out from the slope and Manning's n. The outlet is designed for the largest flow the barrel can carry.

Gabion mattress safety factors. The target factor of safety is SFT = SFB × XC × XM (section 6).

Field	What it is	Default	Range
SFB	Base factor of safety	1.5	1.2 to 2.0
XC	Multiplier for the consequence of failure	1.0	1.0 to 2.0
XM	Multiplier for modelling uncertainty	1.0	1.0 to 2.0

Outlet protection choice. Choose **auto** to bill the cheaper option that works, **rock** for loose rock, or **mattress** for a gabion mattress. The default is auto. Section 6 explains each.

Title block. Client, project (default "Design of Culvert"), consultant, engineer, approved by, and scale (default NTS). These are free text and appear on every drawing sheet and on the report. The client's name heads the title block. Blank fields stay blank.

4. Reading the results page

The results page tells you first whether the design can be issued. It then shows every bill line the design produces. From top to bottom:

1. **Status.**
   - **AUDIT CLEAN - FOR THE ENGINEER'S CHECK AND SEAL**, in green: every check passed.
   - **PRELIMINARY - n AUDIT FAILURE(S)**, in red: at least one check failed.
2. **Count and design hash.** Under the status: how many checks ran, how many failed, and the first 16 characters of the design hash. The hash identifies this exact design and is printed on every drawing sheet and in the DXF. The same inputs always give the same

hash, so it tells you whether two printouts are the same design.

3. **Downloads:** Drawings (PDF), Drawings (DXF), Take-off (XLSX), Calculation report (DOCX) and All (ZIP). See section 8.
4. **Failing checks**, shown only if any failed: the group, the check, what it tests and why it failed. Section 5 explains the groups.
5. **Bill (estimator lines).** Item code, description, unit and quantity for the box itself: excavation, concrete, formwork and reinforcement, in the Road BOQ Estimator's codes. Haulage of aggregates (the E900 items) is not here; the estimator bills it from the road's haul distance.
6. **Outlet scour protection, separate lines.** The outlet protection that is billed (section 6). Each line has a **Location** column saying exactly what it measures, for example "outlet gabion mattress 20 x 9.75 m, 300 mm thick, fill 100-200 mm".
7. **Indicative cost of each outlet option**, where both rock and mattress work. It also says which was billed and why: the cheaper one, or your choice.
8. **Alternative outlet protection, not billed.** The lines for the option you did not bill. They replace the billed outlet lines if you decide to use that option.
9. **Hold-down against flotation, separate lines**, shown only when a hold-down is needed (section 7).

The outlet and hold-down lines are "separate" because the estimator's box module measures the standard box only. Carry these lines into your bill yourself (section 9).

The design form stays below the results, so you can change a value and design again.

5. The audit gate

A design can be issued only when every check passes. A 2/3x3 runs about 79 checks. Each check belongs to one of seven groups:

Group	What it checks
INPUT	Every input is inside its accepted range
DESIGN	Top slab shear, punching under the wheel, bearing pressure, flotation and the hold-down extension
AASHTO	An independent, clause-by-clause check of the bars as drawn, member by member and face by face: flexure, minimum steel, crack control, shear and bar development. It does not reuse the design's own sums.

Group	What it checks
SCOUR	Outlet velocity, scour hole, rock and mattress options, the outlet apron and the outlet cut-off wall
CODEBASIS	Every billed code is in the Items Library; every bar diameter has a bill line; bending-schedule steel equals take-off steel
ESTIMATOR	For the estimator's standard types, the geometry, bars and quantities equal the estimator's own (section 9)
OUTPUT	Every PDF page carries the design hash; the DXF carries the same hash and status, is in millimetres, and its sections measure what was designed

If any check fails, every sheet, the DXF and the take-off are stamped **PRELIMINARY**, and the failing checks are listed on the results page and in the take-off's Audit sheet. Nothing is hidden: a PRELIMINARY design is complete and drawn, but it is not ready to issue.

Common failures and what to try

Check	What it means	What to try
S-apron	Neither rock nor a standard gabion mattress can protect the outlet at this velocity. An energy dissipator is needed.	A flatter slope lowers the full-bore velocity. Otherwise design an energy dissipator separately; the app does not design one.
D-buoyancy	Even a 4 m base extension cannot hold the empty box down.	More fill over the box, or a separate anchorage design.
D-holddown-shear	The base extension fails in shear.	A thicker member (field t).
AASHTO shear or flexure (A-…)	A member is short of capacity at the thickness chosen by rule.	Enter a larger thickness t and design again.
OUTPUT (O-…)	A drawing file does not match the design.	Design again. If it repeats, contact Bespa support with the design hash.

Before issuing a design, read the failing check's detail column. It gives the numbers the check found: demand against capacity, or what was needed against what is available.

6. Outlet scour protection

The app protects the outlet with a flat apron, 20 m long, of loose rock or a gabion mattress. It sizes both, prices both, and bills one.

When protection is needed. The app first finds the outlet velocity and depth at full bore (HEC-14 Chapter 3) and the unprotected scour hole (HEC-14 Chapter 5). Protection is needed if either:

- the outlet velocity exceeds your allowable velocity; or
- the scour hole would be deeper than the standard 0.45 m toe wall.

If neither applies, no protection is billed.

The protected area. The apron is 20 m long and as wide as the concrete apron at its end, between the wingwall tips. The scour hole then forms beyond its end, well clear of the culvert. Inspect the outlet after major floods.

The two options

	Loose rock	Gabion mattress
Method	HEC-14 Eq. 10.6 at the outlet velocity, rounded up to a Table 10.1 rock class	HEC-23 Vol. 2, Design Guideline 10: shear at the outlet against the permissible shear of the fill
Size	D50 from 125 to 550 mm	150, 230 or 300 mm thick
Thickness	Table 10.1 depth: 3.5 × D50 for the 125 mm class, falling to 2 × D50 for 500 and 550 mm	The thinnest standard mattress that is at least 2 × the required d50 and whose fill grading suits
Fill	Rock of the class chosen	75-125 mm for 150 and 230 mm mattresses; 100-200 mm for 300 mm
Pass test	The class is within Table 10.1	Factor of safety ⩾ SFT = SFB × XC × XM (default 1.5)
Bill item	X410.1 Rock filling (m^3)	X420.1 / X420.2 / X420.3 gabion mattress (m^2)

Both options sit on a crushed-stone filter (E667) of the thickness you enter. The excavation is billed by depth band. For a mattress, the mesh aperture must be no larger than the smallest stone divided by 1.25. The drawing and report state this aperture.

Which option is billed

- **auto** (the default) bills the cheaper option that works, priced at the Items Library rates.
- **rock** or **mattress** bills your choice. If your choice does not work for this outlet, the other option is billed and a note says why.
- The option not billed is the **alternative**. Its full set of lines is shown on the results page and on the take-off's **Alternative** sheet, ready to swap in.
- The costs are **indicative**. Check the Items Library rates against your own before you rely on the choice.

If neither works. Rock larger than the 550 mm class or a mattress thicker than 300 mm would be needed. The app does not invent a thicker mattress. It fails check S-apron with "energy dissipator needed", bills no outlet protection, and marks the area in red on the drawing. The design stays PRELIMINARY until you resolve it (section 5).

Outlet cut-off wall. Where the protection goes deeper than the 0.45 m toe wall, the outlet cut-off wall is taken down to the bottom of the protection. It is designed as a reinforced cantilever and billed, extra over the standard toe, as F642.2 (walls up to 300 mm thick) or F643.2 (thicker walls), with its excavation, C30 concrete and bars. A 300 mm mattress on a 150 mm filter needs no deeper wall. A 1.0 m rock apron does.

Example, 2/3x3 at the defaults. The outlet velocity is 4.49 m/s at a depth of 3.0 m. Rock would need D50 500 mm, laid 1.0 m thick, at an indicative GH¢175,625.87. The 300 mm mattress (X420.3, fill 100-200 mm) has a factor of safety of 1.94 against a target of 1.5, at GH¢96,802.25. So auto bills the mattress, and rock goes on the Alternative sheet.

7. Hold-down against flotation

Where the empty box would float, the app extends the base slab past each outer wall until the box is held down with a factor of safety of at least 1.10.

- **Design case.** The box is empty and the water table is at road level, the most severe case. Uplift on the whole box is resisted by its concrete and by the soil above the box and above the extensions. The soil is taken at its submerged weight, from the saturated unit weight you enter. Side friction is ignored, which is conservative.
- **Extension.** The extension grows in 50 mm steps, up to 4 m each side, until the factor of safety reaches 1.10. If 4 m is not enough, check D-buoyancy fails (section 5).
- **Strength.** Each extension is a cantilever from the outer wall. The soil above it holds it down, so its top face is in tension. The bottom slab's bars are carried through to the slab ends. Where those bars are not enough, extra top bars (mark 16) are added and anchored into the slab. Shear in the extension is checked too (D-holddown-shear).

- **Bill.** The extra excavation, lean concrete, blinding, C30 concrete, formwork to the extension edges and the extra bars are listed as separate lines with a Location column. The estimator's standard box does not include them.

For example, a 2/3x3 under 0.6 m of fill needs the base slab extended 900 mm each side, giving a factor of safety of 1.10.

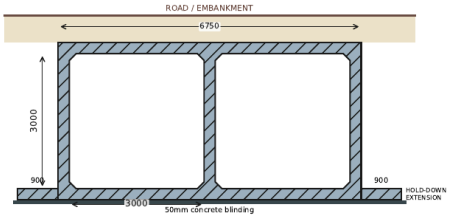
8. The outputs

Each design gives you five files, named after the box (for example 2-3x3), plus a ZIP of all of them.

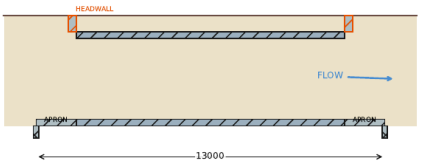
Drawings (PDF). A cover page with the drawing register, then eight A3 sheets. Each sheet has a title block headed by the client's name. Every sheet carries the audit status and the design hash.

Sheet	Title	What it shows
1	General Arrangement	Cross-section, longitudinal section, plan and end elevation, with any hold-down extension
2	Reinforced Section & Moment Envelope	The bars in section and the design moments
3	Top & Bottom Slabs	Slab plans and sections with bar marks
4	End & Interior Walls	Wall reinforcement
5	Wingwall, Apron & Toe Wall	The end structures
6	Bar Bending Schedule	Every bar mark, with a summary in kg by diameter
7	Design Checks & End-Structure Anchorage	Check results, headwall dowels and wingwall anchorage
8	Outlet Scour Protection	Outlet hydraulics, the billed protection in profile and plan, the alternative, and the cut-off wall

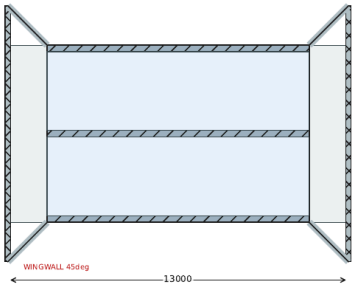
CROSS-SECTION - 2 CELL BOX



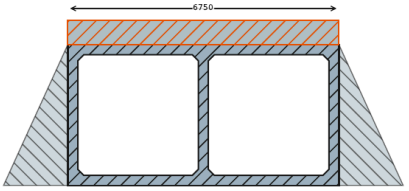
LONGITUDINAL SECTION



PLAN - 2 CELL (apron, toe wall, 45deg wingwalls)



END ELEVATION - 2 CELL (with headwall)



NAME OF CLIENT

NOTES

1. All dimensions are in millimetres except where otherwise stated
2. Structural drawings must be read in conjunction with other relevant documents
3. Concrete to be grade C30 (BS), characteristic cube strength 30N/mm2 at 28 days (design f'c 25N/mm2 cylinder)
4. Minimum cement content to be 360kg/m3
5. Blinding to be lean concrete grade C10, 50mm thick under slabs and bases
6. Maximum size of aggregate should be 20mm
7. Reinforcement to be high yield (fy=420N/mm2)
8. All exposed external corners should have a 25 x 25 chamfer except where otherwise stated

AUDIT CLEAN

Design hash e72d9873ad0f4779

Revision	Signed	Date	Rank

Project

Design of Culvert

2 - 3m x 3m

Description

General Arrangement

Chief Executive

Drawn by Traced by Repro'd by	Designed by Checked by
Passed for Approval Design Consultant	Approved Design Engineer / Approved
Scale NTS	Dwg no. BC-2-01
Date Nov 2026	Sheet no. **1 of 8**

AUDIT CLEAN (79 checks) - FOR THE ENGINEER'S CHECK AND SEAL. Design hash e72d9873ad0f4779

OUTLET - PROFILE ON CENTRELINE




```
OUTLET SCOUR - FHWA HEC-14 (3rd Ed. 2006)
------------------------------------------
Design flow Q = 80.82 m3/s at full bore
  (full-bore capacity, Manning n 0.013 at 0.50%)
per cell 40.41 m3/s;  tailwater TW = 0.00 m

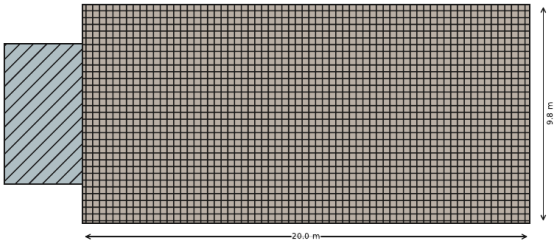
OUTLET (Ch. 3)
  full bore, outlet flowing full (3.1.1)
  yo = 3.00 m  Vo = 4.49 m/s  Fr = 0.83

UNPROTECTED SCOUR HOLE (Ch. 5)
  hs = 4.34 m  Ws = 21.3 m  Ls = 40.0 m
  Eq. 5.1, Rc = 0.750 m, sigma = 1.87

FLAT OUTLET APRON (ruling 31 Oct 2026)
  20 m long x 9.75 m (concrete apron end width)
  GABION MATTRESS (HEC-23 Vol 2, DG10)
  X420.3, 300 mm thick
  fill 100-200 mm (ASTM D6711), d50 150 mm
  tau_des 125 Pa (Eq. 10.7), tau_p 243 Pa
  F.S. 1.94 >= SFT 1.50
  mesh aperture <= 80 mm (stone/1.25)
  alternative, not billed: rock D50 500 mm
  billed: the cheaper option
  scour forms beyond, 21.5 m from the barrel
  filter 150 mm crushed stone (HEC-11)
  outlet cut-off wall 450 mm deep

Inspect after major floods (HEC-14 10.2).
```

OUTLET - PLAN OF GABION MATTRESS



NAME OF CLIENT

NOTES

1. All dimensions are in millimetres except where otherwise stated
2. Structural drawings must be read in conjunction with other relevant documents
3. Concrete to be grade C30 (BS), characteristic cube strength 30N/mm2 at 28 days (design f'c 25N/mm2 cylinder)
4. Minimum cement content to be 360kg/m3
5. Blinding to be lean concrete grade C10, 50mm thick under slabs and bases
6. Maximum size of aggregate should be 20mm
7. Reinforcement to be high yield (fy=420N/mm2)
8. All exposed external corners should have a 25 x 25 chamfer except where otherwise stated

AUDIT CLEAN

Design hash e72d9873ad0f4779

Revision	Signed	Date	Rank

Project

Design of Culvert

2 - 3m x 3m

Description

Outlet Scour Protection (HEC-14)

Chief Executive

Drawn by Traced by Repro'd by	Designed by Checked by
Passed for Approval Design Consultant	Approved Design Engineer / Approved
Scale NTS	Dwg no. BC-2-08
Date Nov 2026	Sheet no. **8 of 8**

AUDIT CLEAN (79 checks) - FOR THE ENGINEER'S CHECK AND SEAL. Design hash e72d9873ad0f4779

Drawings (DXF). The same views at true scale in millimetres, on separate layers (concrete, reinforcement, dimensions, text, fill, ground, blinding and centre lines). Its header carries the design hash and the audit status. The DXF is written to the open DXF standard (R2010). Open a copy in your CAD package and check it before you rely on it.

Take-off (XLSX).

Sheet	What it holds
Bill	The estimator lines for the box, then the hold-down and outlet lines with their Location column and the indicative cost of each outlet option
Alternative	The outlet option not billed, its lines, and both indicative costs; shown only when both options work
Scour	The outlet hydraulics, the scour hole, and both protection options with their figures (rock class; mattress shear, factor of safety, grading and mesh)
Dimensions	The dimension-paper measurement behind each quantity
Bending Schedule	Bar marks, diameters, lengths, numbers and masses
Audit	Every check with its result and detail
Geometry	The dimensions the design used

Calculation report (DOCX). The design basis, member design, checks, the outlet scour design with both options, and the audit gate, with the drawing sheets embedded. It can be edited in Word for your own submission.

All (ZIP). The four files above plus results.json, the complete design record. Keep it with the project file: the design hash in it identifies the design.

9. Using the take-off with the Road BOQ Estimator

The app measures the box with the estimator's own box module, so the box lines it bills are the lines the estimator bills.

Standard boxes. The estimator carries 19 standard box types. Your design is a standard box when it is one of those types and leaves these inputs at their defaults: fill 0.6 m, haunch 0.15 m, apron 1.5 m, headwall 0.6 m, wingwalls 45° and thickness 0 (by rule). For a

standard box, the ESTIMATOR checks confirm that the geometry, bars and every quantity equal the estimator's own for that type and length.

1. In the estimator, enter the box at its chainage as that standard type. Its box lines will match the app's "Bill (estimator lines)".
2. Add the app's **outlet scour** lines and any **hold-down** lines to your bill yourself. The estimator's standard box does not include them.
3. Leave haulage to the estimator. It bills aggregate haulage (E900 items) from the road's haul distance.

Other boxes. Any other size or input is designed and billed in the same item codes. The ESTIMATOR checks report "parity does not apply". The estimator cannot produce these lines, so carry the whole bill from the app's take-off into your BOQ.

The alternative. Lines on the Alternative sheet are for your decision only. Never bill both options. If you choose the alternative, it replaces the billed outlet lines, item for item.

Rates. The indicative costs use the rates in the Items Library. Your BOQ is priced at your project's rates.

10. Limits, troubleshooting and a worked example

Limits and your responsibility

- **The engineer decides.** The app gives a checked design, not a sealed one. A licensed engineer must check the design, the site conditions and the inputs, and seal it before construction.
- **The design envelope.** The input ranges are the conditions the method holds over: up to 4 cells, spans up to 6 m, heights up to 5 m, and at least 0.6 m of fill. Fatigue is not checked, because of that minimum fill.
- **Flow.** The design flow is the barrel's full-bore capacity. The app does no catchment hydrology. Size the opening for your design flood separately.
- **Outlet only.** Scour protection is designed at the outlet. The inlet keeps the standard 0.45 m toe wall.
- **Mattress method.** Design Guideline 10 is written for channel beds. The app applies it at the culvert outlet, using the outlet velocity and depth, and says so in the check.
- **No energy dissipators.** Where neither rock nor a mattress works, the app flags the design and stops (section 6).
- **Flotation.** Side friction is ignored, which is conservative.
- **CAD.** Check the DXF in your own CAD package before you rely on it.

Troubleshooting

What you see	What to do
The form comes back with a red message	A value is outside its range or not a number. Correct each field named in the message.
The sign-in page refuses your key	Check that your subscription is active, and that you pasted the key exactly as it appears in the issuing email.
A design takes longer than usual	Another design is running. Yours starts when it finishes.
A download link no longer works	Files are deleted after 24 hours. Design again: the same inputs give the same design and hash.
The status is PRELIMINARY	Read the failing checks (section 5) and change the inputs, or resolve the issue outside the app.

Worked example: 2/3x3 at the defaults

1. Enter n = 2, B = 3.0, H = 3.0 and press **Design**. Leave every other field at its default.
2. The status reads AUDIT CLEAN, with 79 checks and 0 failed.
3. The bill lists the estimator lines for the 2/3x3 box.
4. Hold-down: the base slab is extended 900 mm each side (factor of safety 1.10). Its lines appear under "Hold-down against flotation".
5. The outlet velocity is 4.49 m/s, so protection is needed over 20 m × 9.75 m. Auto bills the 300 mm gabion mattress, X420.3, 195 m², on a 29.25 m³ filter with 88 m³ of excavation. Its indicative cost is GH¢96,802.25, against GH¢175,625.87 for rock.
6. The rock alternative (X410.1, 195 m³, with a 1.15 m deep cut-off wall billed under F642.2) appears on the results page and the Alternative sheet.
7. Download **All (ZIP)** and keep it with the project file.