# SAMPLE

## Building Tomorrow's Engineers

The Margin's Keeper in the Machine Era

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# Introduction

An engineer is somebody who is trusted with a number that other people will stand on.

This book is about the work behind that trust: what an engineer actually holds, what the trade has decided to call good practice, and how the work changes when the tools do. It is written for people who are considering the trade, for people already inside it and wondering whether they have understood it correctly, and for the people who manage engineers without ever having been one.

The claim of the book is narrow and arguable. Engineering is not the production of precise calculations, though precision is one of its tools. It is the deliberate holding of margin: an allowance, larger than the calculation strictly requires, whose size and location somebody has to justify, record, and defend years later when the thing is built and the person who justified it has moved on.

Two folklores stand in the way of that understanding. The first is the calculator, for whom the work is the number and the number's accuracy is the whole virtue. The second is the over-builder, for whom strength is safety and more material is always safer. Both are wrong in the same direction: they remove the judgement that margin actually requires, one by hiding it inside precision and the other by hiding it inside mass.

The chapters that follow take the trade apart in the same order as the rest of this collection. The keeper comes first, then the territories the trade splits into, then the routes people take into it, the working day, the craft of the keeper itself, the strain it puts on the person, the conversations it requires, the instruments it depends on, a composite year, and the long arc of a career.

Nothing in this book assumes a particular discipline. Care has been taken to describe the practices that civil, mechanical, electrical, chemical and systems engineers share, and to mark clearly where they diverge. Where an example is specific enough to seem like one trade, that is deliberate: a practice is easier to see in a particular case than in an abstract one.

Some readers will want a book that tells them which tools to learn. This is not that book, and the omission is deliberate. Tools change faster than the trade's judgement does, and a reader who understands margin, load, inspection and handover can learn the current tooling of any discipline in a few months. A reader who has learned only the tooling will spend a career confusing fluency

with competence.

The machine era arrives in these pages as a change in the instruments, not as a change in the keeper. Computation has made analysis cheap and iteration fast, which is genuinely better than what came before. It has also made it easy to produce a confident number that nobody has interrogated, and easy to build a model that is precise about the wrong geometry. The trade's response is not to refuse the instruments. It is to move the judgement earlier, into the framing of the question and the choice of the margin, and to insist that the record of that judgement survive the project.

That record is the thread running through the book. The drawing, the calculation file, the assumption list, the sign-off, the as-built, the handover pack: these are how an engineer speaks to people who will never meet them. A margin that exists only in somebody's head is not a margin. It is a hope with a number attached.

# Chapter 1 — The Margin

## What a Margin Is

A margin is the distance between what a thing must do and what it is built to do, and the distance is chosen by a person. That is the whole of the definition, and every difficulty in this trade lives inside the word chosen.

Consider a beam that analysis says must carry forty kilonewtons. The engineer does not specify a beam that carries forty. They specify one that carries sixty, or eighty, and the extra is the margin. It is not waste, and it is not caution in the ordinary sense of a nervous person adding a bit. It is a reasoned allowance for the things the analysis could not include: the load that will be added later by a building services engineer, the steel that will be a little under its nominal thickness, the connection that will be fabricated a little out of position, the inspection that will miss what it is looking for, and the fact that a public structure must survive not only the loads its designer imagined but the ones nobody imagined.

The margin has three properties that matter. It is deliberate, meaning somebody decided its size rather than inheriting it. It is located, meaning it sits somewhere specific in the design and that location is known. And it is recorded, meaning the reason for it survives in a document that a stranger can read after the engineer has left the project.

An engineer who cannot say where the margin is, how big it is, and why that size, is not holding the margin. They are relying on one and hoping. The difference is invisible in a finished structure and decisive in a dispute, an investigation, or a modification fifteen years later.

## The Two Folklores

Every trade has stories that make the work legible to outsiders and misleading to insiders, and this one has two.

The first is the calculator: the belief that engineering is the production of an accurate number, and that the person with the most precise answer is the best engineer. This folklore is attractive because it is measurable and because software makes it feel more true every year. It produces engineers who can run an analysis nobody in the room can check, and who cannot say what would happen if the load were doubled. Precision is a tool. The question of what to compute, at what fidelity, with what assumption about the world, is the work, and it is not arithmetic.

The second is the over-builder: the belief that more material is safer, that a thicker plate cannot hurt, and that the conservative choice is always to add. This folklore is attractive because it appears to be safe and cannot be criticised in the moment. It fails in three ways. It moves the failure somewhere else, usually into a connection or a foundation that now carries more weight than it was sized for. It spends money that was going to be spent on something with a real safety function. And it trains the organisation to treat every engineering judgement as a request for more, which is the fastest way to make engineering advice ignorable.

Both folklores share a structure: they replace judgement with a single virtue, and they make the person who asks a further question look inexperienced.

## Where Margin Lives

Practitioners new to the trade look for margin in one place, usually in extra thickness or a higher grade of material, and are surprised to find it distributed across several quite different things.

There is margin in material, which is the obvious one. There is margin in geometry, where a shape is chosen so that a local defect matters less, which often costs nothing. There is margin in redundancy, where a load has two paths to the ground so that the loss of one is survivable; this is usually the cheapest and most robust form and the one most often cut when a project is tight. There is margin in tolerance, where the specification permits a range of positions or dimensions and the design has been checked at the edges of that range rather than at its centre. There is margin in maintenance access, where somebody decided that a component could be reached and replaced, which converts a future failure into a future repair.

And there is margin in time. The inspection that happens, the test that is run before handover, the commissioning sequence that loads the system gradually while somebody watches: these hold margin in the schedule rather than in the material, and they are the first thing removed when a programme slips.

An engineer who can name which of these carries the margin on a given design is doing the trade. An engineer who can only say that the numbers work has a number.

## The Three Commitments

This book's argument rests on three commitments, and they are offered as a description of what the trade already considers good practice rather than as a

reform.

The first is to name the load and the limit before choosing the form. What must this carry, in what conditions, for how long, and what happens when it does not. Every design decision downstream inherits the answer to that question, and a design begun before the question is answered will have its real load chosen by its shape rather than the reverse.

The second is to make the margin explicit rather than accidental. A margin that nobody chose is still a margin, and it will be spent by somebody who does not know it exists. The practice is to state the size, state the location, and state the reason, in a document that a stranger can read.

The third is to assume your instruction will be carried out by somebody who cannot ask you a question. This is the hardest and most distinctively engineering commitment. The drawing, the specification and the procedure are not a record of what the engineer thought. They are the only channel through which that thought reaches the person who pours the concrete, bends the conduit or torques the bolt, and anything the engineer leaves implicit will be resolved by that person's habit rather than the engineer's intention.

## The Load That Will Not Be Known

Every design is an answer to a question about loads, and a proportion of that question is permanently unanswerable.

Some loads are known with reasonable precision: the weight of the material itself, the water in a tank of stated capacity, the equipment listed on the drawing. Some are known statistically: wind, snow, traffic, occupancy, where the code offers a distribution derived from records. And some are simply not knowable at the design stage, because they depend on decisions that have not been made by people who have not been appointed.

A building's future use is the clearest case. The designer knows it will be an office, and does not know that in eleven years a floor will hold a server room, or that a tenant will install a compactus filing system whose point loads bear no relation to the office loading in the code. The code specifies a floor load for office use precisely because this is the best available answer to an unanswerable question, and its adequacy depends on somebody remembering that it is a convention rather than a measurement.

The trade's habit of stating the assumed load in the design record is the only defence. A slab designed for five kilonewtons per square metre and labelled as

such can be assessed when the tenant arrives; one designed to the code's number without comment invites the assumption that it will hold whatever a floor of that description is expected to hold. The difference costs one line of text and it is the difference between a structure that can be managed and one that can only be trusted.

## The Reasonable Engineer

The law and the profession both judge engineering conduct against a standard that is deliberately not perfection, and the standard is worth understanding because it shapes ordinary decisions.

The standard is usually expressed as what a reasonable and competent practitioner in the same field would have done in the same circumstances. It is a comparative test, not an absolute one, and its effect is to make the ordinary practice of the trade the benchmark for individual conduct. An engineer who followed a method that competent peers would have used is generally in a defensible position even when the outcome is poor; one who departed from that method without reason is exposed even if the outcome is fine.

Two consequences follow that beginners find surprising. The first is that being right by luck is not a defence, because the test is about the process rather than the result. The second is that the benchmark moves: methods that were reasonable twenty years ago are not automatically reasonable now, and an engineer who has not updated is measured against current practice rather than against the practice of their training.

This is why the trade's habit of recording reasons matters beyond tidiness. A design decision recorded with its basis can be assessed against the standard of the day; a decision with no recorded basis can only be assessed by its outcome, which is the harshest possible test and the one that produces injustice in both directions.

## What a Margin Is Not

Three things are routinely confused with margin and each confusion has a cost.

The first is conservatism of temperament. An engineer who adds material because uncertainty makes them uncomfortable is not holding a margin; they are transferring their discomfort into the structure, where it may sit in the wrong place. The distinguishing feature of a real margin is that its size can be justified in a sentence that mentions the specific uncertainties it addresses.

The second is a safety factor borrowed from a code. A code factor addresses the uncertainties the code's authors had in mind for the structure type it covers. It does not address the ones created by the particular project: the novel connection, the restricted site, the contractor's proposed sequence, the client's intention to add two floors in a later phase. Applying the code factor to a situation outside the code's scope is arithmetic performed on a question that was never asked.

The third is spare capacity discovered afterwards. A structure that turns out to have been built heavier than the drawing specified has a reserve; it does not have a margin, because nobody chose the reserve, nobody knows its size, and nobody will account for it when the next change is made. Reserve is a fact about a structure. Margin is a decision about a design, and only the second can be managed.

## The Sentence That Justifies It

Practitioners who are good at this work share a habit that is easy to describe and hard to acquire: they can state the basis of a margin in one sentence that a stranger could check.

The sentence has a shape. It names the uncertainty, names the allowance, and names the consequence if the allowance proves insufficient. The ground is variable across the footprint, so the footing is sized for the weaker of the two logged strata, which is adequate unless the made ground extends further than the boreholes indicate, in which case the settlement will be uneven and the slab will crack rather than the structure fail.

Four elements in one sentence: the uncertainty, the allowance, the residual risk, and the consequence. An engineer who can produce that sentence for each significant decision has done the work. An engineer who cannot has made the decisions anyway, and simply has not examined them.

The sentence is also the unit of review. A reviewer who reads a list of these sentences learns more in ten minutes than from an hour with the drawings, because the list is the design's actual reasoning and the drawings are only its expression.

## Margin in a World of Optimisation

Computational optimisation has made it cheap to remove material until a structure is exactly adequate, and the trade is still working out how to respond.

The technique is straightforward. Define an objective, usually mass or cost, define constraints, usually stress and deflection limits, and let the software find the shape that satisfies the constraints with the least material. The results are elegant and they are, within their terms, correct. What they are not is robust, because robustness was not in the objective.

The missing quantities are the ones a human engineer carries as habit: tolerance for construction, allowance for a future change of use, reserve for a load case nobody specified, the capacity to be inspected, the ability to be repaired rather than replaced. None of these can be optimised unless they are written as constraints, and writing them as constraints requires somebody to have decided what they are worth.

The practitioners who use optimisation well do so in the middle of a design rather than at its end. They optimise to explore, keep the options that differ in kind rather than in degree, and then choose among them on grounds that include everything the objective left out. The tool finds candidates. The engineer chooses, and the choice is the margin.

## The Margin Someone Else Will Spend

A margin belongs to whoever knows about it, and the trade's arrangements for transferring that knowledge are imperfect in a way that produces most of its long-term failures.

An organisation holds margin in three places: in its designs, in its records, and in its people. The first is durable and inert. The second is durable and readable. The third is neither, and it is where the trade's practitioners habitually store the most important part, because it is the cheapest place to put it.

When a person leaves, the margin that lived in their head becomes inaccessible. The structure still has reserve, and nobody can say how much, which means the next modification will be assessed against a conservative reading of the drawings, and the conservative reading will be wrong in the direction of wasting the reserve or in the direction of exceeding it, depending on which way the engineer's habit runs.

The remedy is the least glamorous practice in this book. Write the margin down, in the place the next person will look, in language they will understand without you. Every firm believes it does this. The evidence that a firm actually does it is that a new engineer can answer, within an hour of asking, how much

margin a five-year-old structure has and where it sits.

## The Cost of the Margin

A margin is not free, and pretending otherwise is why engineers lose arguments about it.

The cost is material and it is visible: a heavier member, a thicker plate, an extra pile, a larger pump. It appears in the bill of quantities with a number beside it, and it is the first thing a cost consultant identifies when a project is over budget. The benefit, by contrast, appears in events that do not occur, and events that do not occur have no line in any account.

The trade's failing is that it has never learned to present the benefit in a form that competes. A structural engineer who says that the extra steel is for robustness is met with a request to quantify it, and the quantification is difficult because the honest answer is a probability distribution over failures that nobody has experienced. The result is that the argument is lost in the meeting and the margin is removed.

The practitioners who win this argument do not argue about probability. They argue about consequence and about precedent. What happens if it is not there, in physical terms, described for the specific building. What the maintenance consequence is. What the equivalent structure did in a comparable event. And, most effectively, what the cost of alteration later would be if the margin were absent, because that cost is real, is quantifiable, and is paid by somebody who will still be in the organisation in ten years.

## The Margin Nobody Chose

Some margin in every built thing was never decided by anybody, and it is worth knowing how it arises because it behaves differently.

It arises from rounding, since a member is chosen from a catalogue and the next size up is rarely exactly what the calculation required. It arises from standardisation, since a firm's detail uses the same thickness everywhere for simplicity. It arises from manufacturer's tolerances, since the delivered product is at least as strong as its nominal value by requirement. And it arises from conservatism in a supplier's published figures, since the supplier's data is a floor rather than a mean.

The total is often substantial, frequently a quarter of the capacity. It is invisible because it belongs to no single decision, and its invisibility has two

consequences. The first is that a structure is safer than its calculation implies, which is fortunate and undirected. The second is that when somebody later wants to add load, the calculation they consult shows little spare capacity while the structure actually has plenty, and the response is either unnecessary strengthening or, worse, a decision based on the calculation's view alone.

Capturing this margin is a matter of documenting the actual as-built section sizes and material grades rather than only the design requirement. A structure's real capacity is a property of what was installed, and the installed thing is frequently better than what was specified, which is a fact worth recording and almost never recorded.

## When the Margin Is in the Wrong Place

Margin placed badly is worse than margin absent, because it creates confidence that is not supported.

The clearest case is margin added to a member while the connection that carries it remains at its limit. The member is now stronger than the joint, and the failure mode has moved from a ductile one to a brittle one without anybody deciding that. A structure that fails at a connection is a structure that fails suddenly, and sudden failure is the outcome the trade's margins exist to prevent.

The second case is margin added uniformly, which is what a global factor does. It strengthens everything equally, including the parts that were never at risk, and it leaves the genuinely critical element with the same relative reserve as before. The practitioner's question is not how much margin, but margin on what, and the second question is the one that determines whether the allowance does any work.

The third case is margin in the analysis rather than the structure. A designer who models a support as fixed and provides a pinned detail has not added margin to the design; they have added an error to the calculation, and the error is in the unconservative direction if the real behaviour attracts less load than the model assumed. Documenting the model's assumptions is the only defence, and it is the part of the record that nobody reads until something has gone wrong.

Good practice in this territory is specific: identify the failure mode that must be ductile, ensure the reserve is in the element that yields rather than the one that fractures, and record the choice. It is a rule a young engineer can apply

from the first year, and senior engineers still get it wrong when they are moving quickly.

## The Retrofit Question

Most of the world's structures are not new, and the practitioner's most common task in a mature economy is deciding what can be done with what already exists.

A retrofit assessment begins with the same question as a new design, which is what the thing must carry, and it then meets the difficulty that makes retrofit a separate skill: the existing structure's capacity is not known and cannot be inspected fully. The drawings may be wrong, the material may be stronger or weaker than specified, and the critical element may be buried.

The trade's response is staged investigation. Start with the documents, then with non-destructive examination, then with a small number of targeted openings or cores, and only then with analysis. The order matters because each stage is cheap relative to the next, and a project that begins with analysis is one that will later discover its model was founded on a drawing that was never accurate.

The second element is the honest statement of what was not found. An assessment that says the capacity is adequate without stating what was investigated invites the reader to believe the structure was verified. One that says the capacity is adequate on the basis of two cores, the original drawings and a visual survey, with the untested elements named, allows a decision to be made about the residual risk by the person who owns it.

## The Thing That Cannot Be Calculated

Some properties of a good design cannot be analysed and they determine whether it works, which is the part of the trade that resists teaching.

The first is simplicity. A simple structure is easier to build, easier to inspect, easier to understand and easier to modify, and none of that appears in any calculation. The practitioner who chooses the simple arrangement over the efficient one has made a judgement about the whole life of the thing and is frequently described as conservative by people who are only counting material.

The second is tolerance of the unexpected. A design with redundancy, ductility and accessible inspection can absorb a load nobody anticipated and a detail

nobody built as drawn. A design optimised to its limits cannot, and the difference will not be visible until the day the unexpected arrives.

The third is legibility to the people who will build it. A drawing that a fabricator can read without calling is a drawing that will be built as intended, and the quality of the drawing's legibility is a design decision rather than a drafting one.

These properties are the trade's real craft, they are learned by watching somebody who has them, and they are the reason a firm's most senior engineer is worth consulting even on a straightforward project.

## The Shape of a Defence

When an engineering decision is questioned, whether in a review, a claim or an inquiry, the defence that holds is a shape rather than a story.

The shape has four parts. What the requirement was, and where it came from. What was decided, and what alternatives were considered. What the decision relied on, stated as assumptions with their basis. And what was checked, by whom, and what the check consisted of. A practitioner who can produce those four parts for a significant decision is in a defensible position whatever the outcome.

What fails is the narrative defence: a recollection of how the project went, delivered persuasively after the fact. It is persuasive in conversation and inadequate in writing, and the moment it meets a document it dissolves, because the narrative is reconstructed and the document is contemporaneous.

This is the practical reason for the record-keeping described throughout the book, and it is worth separating from the ethical reason. The ethical reason is that the margin must be transferred to the next person. The practical reason is that the transfer is also what protects the practitioner. These are the same practice serving two purposes, which is why the trade's emphasis on documentation survives in organisations that have no interest in ethics at all.

## The Two Readers

Every document an engineer writes has two readers, and the failure to write for the second is the commonest weakness in the trade's literature.

The first reader is the one in front of the work: the reviewer, the contractor, the client, who has context and can ask a question. The second is a person twenty years later with a specific problem and no context at all. They will be

reading the same document and they will not be able to ask anything.

Writing for the second reader means stating things the first reader would find obvious: what the structure is for, what it sits on, what was assumed, what changed. It means avoiding abbreviations that were obvious at the time. It means recording the reason for a decision rather than only its content, because the content is visible in the drawing and the reason is not.

The test that a practitioner can apply is simple and slightly humiliating: could a competent stranger, with this document and nothing else, answer a question about this design in an hour. If the answer is no, the document is a private note with a professional appearance, and the difference will be paid by somebody who was not in the room.

# ABOUT THE AUTHOR

Aiman JoeHanz writes the Building Tomorrow's People series, and the engineering volume is its argument about margin: the trade that must design for loads and failures it hopes never to see. It covers the specification that omits the load case, the factor of safety as a social agreement, the test that passes because the fixture was built to pass, the sign-off that travels with the drawing, and the simulation that now arrives before the prototype. The book is about the cost of being believed.