Design of A Stable Traffic Cone

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by

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To those that bring light to my life spirit: above all, the Buddha; my precious children Ching-Ren, Ching-Yuan and my niece Joice; their grandparents, Jui-Ho Lee and Kuo-Ying Chao; and special thanks to my wonderful wife Hsiang-Li, for all her support and encouragement.

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List of Abbreviations

ASTM	American Society for Testing Material
CFD	computational fluid dynamics
DFM	design for manufacture
DFA	design for assembly
DFE	design for the environment
EPDM	ethylene propylene diene monomer
FEA	finite element analysis
FMEA	failure modes and effects analysis
PDS	product design specification
QFD	quality function deployment
SOP	subtract and operate procedure

Chapter 1

Introduction

1. Introduction

1.1 Background

Traffic cones are a common sight on roads in most countries but due to their commonplace nature people tend not to think too much about their design and the importance of them in maintaining safe traffic flow is often overlooked. Traffic cones have become a product that is taken for granted in daily life for most people. Traffic cones are so easy to see on the road and yet are readily neglected by people. Never the less traffic cones are still important for safety and guiding traffic flow even though they are so simple.

A traffic cone consists of a relatively thin walled cone above a square hollow base. In order to increase the cones stability, the base is usually weighted therefore lowering the centre of gravity of the entire traffic cone. Traffic cones are typically produced in plastic or composite materials for reasons of safety and cost.

A literature search of a range of books and professional magazines has turned up little related research and few reports on the topic of traffic or road cones. It appears that road- cones receive little attention by people, due to their simple profile and inexpensive production cost.

A big problem with current traffic cones is the ease with which they topple over when on the road. This project was undertaken with a Tauranga based company called ITS which is a rotational plastic moulding R&D, design and manufacturing company. ITS wants to redesign the traffic cone to counter the deficiencies of existing products and increase the stability of the cones during service. A prototype of a newly designed traffic cone concept was created in this project, the dimensions being set according to the Code Of Practice For Temporary Traffic Management by Transit NZ (Appendix A). The prototype and traffic cones currently used on roads are not much different in appearance, but there are obvious differences in the design. The key points of difference are as follows:

(i) Current traffic cones are produced as a single body, therefore the upper part of the cone and the base are unable to be separated. The prototype was designed with a partition between the cone and the base, and these were connected using four rubber strips. These served both to secure the cone to the base and also to support its weight.

(ii) The base of traffic cones in current use is rigid or near-rigid. Whereas the base of the prototype cone consists of flexible rubber.

1.2 The reason for re-design

Most current products are designed with a considerable amount of weight in the base in order to increase the stability of the traffic cone, which consumes a relatively large amount of material. Stability cannot be significantly increased using this design strategy without increasing the amount of material and the cost of production. Therefore optimization of the design to improve flexibility and stability would be investigated without compromising the appearance or manufacturing costs.

1.3 Aims and Objectives

The aims and objectives of this research were to:

(i) Create several solid 3D computer models using dimensions in the 3D model which conform with the prototype and other simulations.

(ii) Determine the properties of rubber experimentally so that the data can be used in simulations.

(iii) Input the data obtained from the experimental work into a 3D model to create an accurate simulation. The results of the computerized simulation and the experimental work are compared with each other, and the parameters and variables in the simulation adjusted to match the real experimental situation.

(iv) Set up a mathematical model for deduction and analysis to strengthen the deficiencies of the 3D model simulation.

(v) Establish a valid model which can be used to investigate the effects of changes in cone profile or materials so that the design of the cone can be optimized.

Chapter 2

Literature Review

2. Literature Review

2.1 Product Design

Product design is the process of developing an initial concept, in order to achieve the needs and demands of the consumer. It is a task which is extensively undertaken in almost every product-based industry, such as for tools, machinery, furniture, clothes and even food. Product design may require knowledge of many different areas, including mathematics, physics, chemistry, cost analysis, fabrication processes and aesthetical considerations, all of which ultimately relate to profit. Design may be a continuously ongoing process – keep looking for the best way to meet the customers needs and requirements by modifying the product design.

There are two principle design methodologies: 'descriptive methodology' addressing the essential structure of design, and 'prescriptive methodology' relating to how the design process should be approached effectively (Roozenburg & Eekels, 1991). Descriptive models of the design process usually emphasise the importance of generating a solution concept early in the process, thus reflecting the solution-focused nature of design thinking. This initial solution hypothesis is then subjected to analysis, evaluation, refinement and development. Sometimes the analysis and evaluation show up fundamental flaws in the initial theory and it has to he abandoned, and a new concept generated and the cycle started again. The process is heuristic: using previous experience and general guidelines that lead to what the designer hopes to be the right direction, but with no absolute guarantee of success (Cross, 1989). Cross (1984) developed a four-stage descriptive model of the design process, based on the essential activities that the design performs, see Figure 2-1. The end- point of the process is the communication of a design, ready for manufacture. French (1985) developed a more detailed model based on the following activities of design, see Figure 2-2:

i) Analysis of problem,

ii) Conceptual design,

iii) Embodiment of schemes,

iv) Detailing.

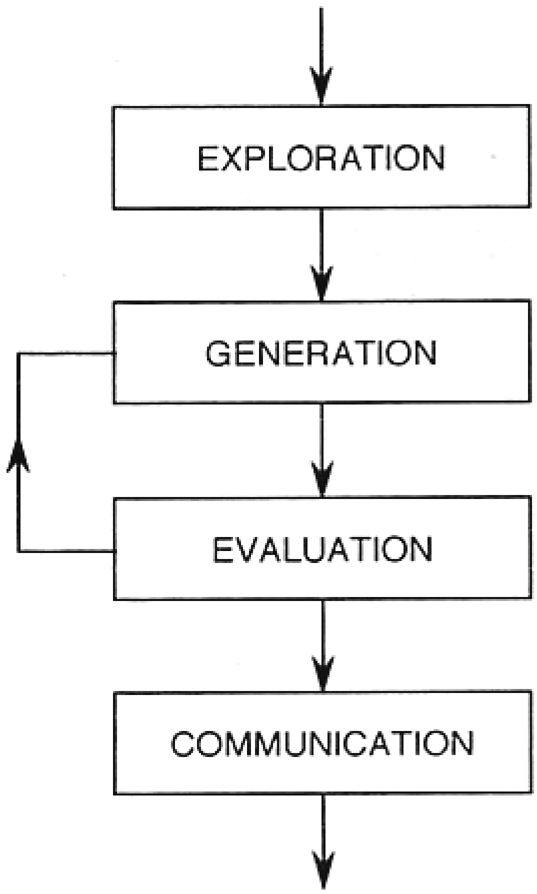


Figure 2-1 Four-stage Descriptive design process model (Cross, 1984)

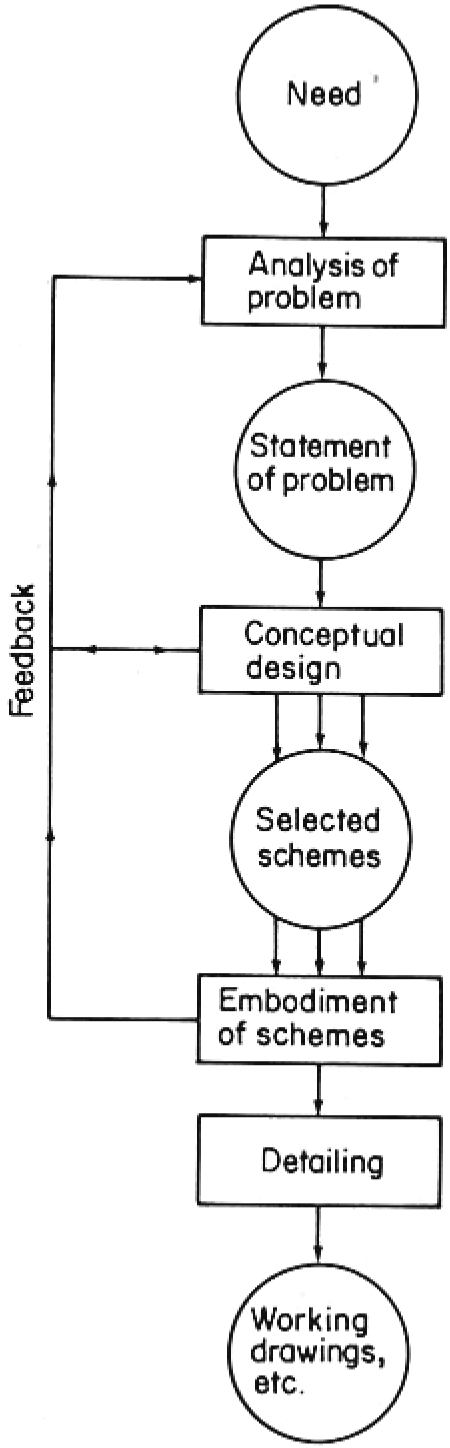


Figure 2-2 Detailed Descriptive design process model (French, 1985)

Prescriptive or normative design methodology forms an opinion based on descriptive analyses, and recommends for certain problems the application of certain methods. Prescriptive design methodologies are not limited to the assortment of methods found in a descriptive manner, but must also construct new methods if for a certain part of the design process no satisfactory methods are available (Roozenburg & Eekels, 1991). These models suggest a basic structure to the design process of Analysis, Synthesis, and Evaluation (Jones, 1984):

i) Analysis consists of listing all design requirements and the reduction of these to a complete set of logically related performance specifications.

ii) Synthesis refers to finding possible solutions for each individual performance specification and building up complete designs from these with the least possible compromise.

iii) Evaluating the accuracy with which alternative designs fulfil performance requirement for operation, manufacture and sales before the final design is selected.

Archer (1984) developed a more detailed prescriptive model, see Figure 2-3. This model includes interactions with the world outside of the design process itself, such as inputs from the client, the designer’s training and experience, other sources of information, etc. The output is the communication of a specific solution. These various inputs and outputs are shown as external to the design process in the flow diagram, which also features many feedback loops. This process was summarized by dividing it into three broad phases: Analytical, Creative and Executive (Archer, 1984), see Figure2-4.

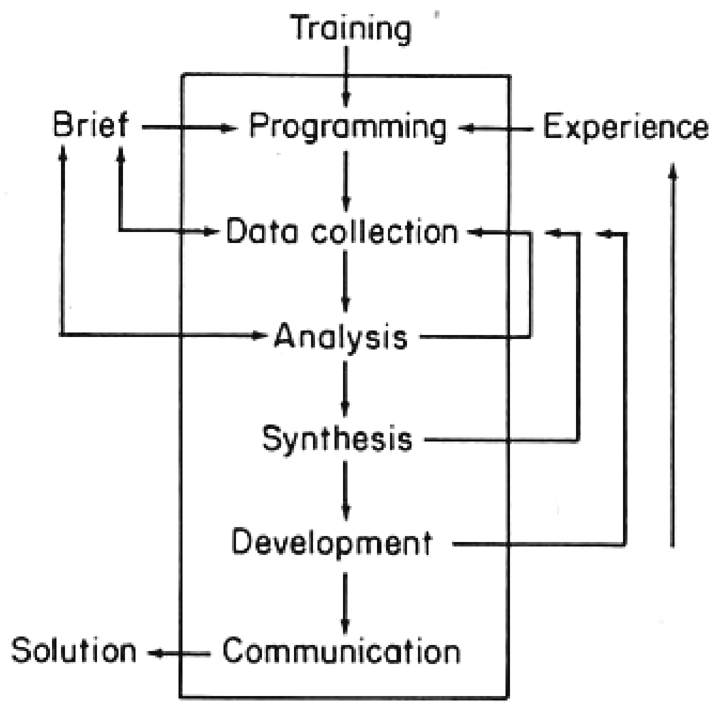


Figure 2-3 Detailed Prescriptive design process model (Archer, 1984)

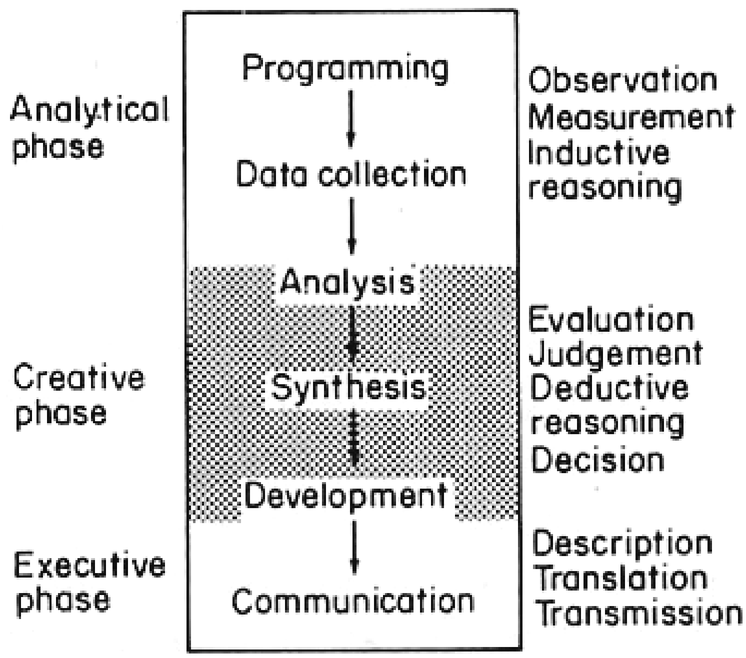


Figure 2-4 Three-phase summery of the Prescriptive design process (Archer, 1984)

A good product design can lead to a successful development. The design can be assessed based upon product functionality, the practicability of assembly, cost of manufacturing, marketing response, and how these factors in combination influence whether the product design reaches the requirements demanded by the customer. A good product design links functionality, customer needs and market requirements to achieve benefit at minimum cost. So, several main factors should be considered during the process of product design as follows:

(i) customer needs
(ii) product specifications
(iii) generating concept
(iv) selecting concept
(v) developing the concept
(vi) final design for product

2.2 Customer needs

The philosophy behind this factor is to create a high-quality information channel that runs directly between customers in the target market and the developers of the product. It is built on the premise that those who directly control the details of the product, including the engineers and industrial designers, must interact with customers and experience the use environment of the product. Without this direct experience, technical trade-offs are not likely to be made correctly, innovative solution to customer needs may never be discovered, and the development team may never develop a deep commitment to meeting customer needs (Cross, 1989).

Ulrich (2004) stated that identifying customer needs is an integral part of the concept development phase of the product development process. The resulting information is used to guide the team in establishing product specifications, generating product concepts, and selecting a product concept for further development. Therefore, the process of identifying customer needs includes five steps:

(i) Gather raw data from customers.

(ii) Interpret raw data in terms of customer needs.

(iii) Organize the needs into a hierarchy.

(iv) Establish the relative importance of the needs.

(v) Reflect on the results and the process.

The Kano diagram (Shiba, Graham, and Walden, 1993) depicted the idea that one might consider customer satisfaction on a scale from dissatisfied to satisfied, see figure 2-5. In this diagram the function of a product can be related to customer requirement or satisfaction, a line using plotted at 45˚, which indicates the degree to which the design of a product accords with the customer's expectation.

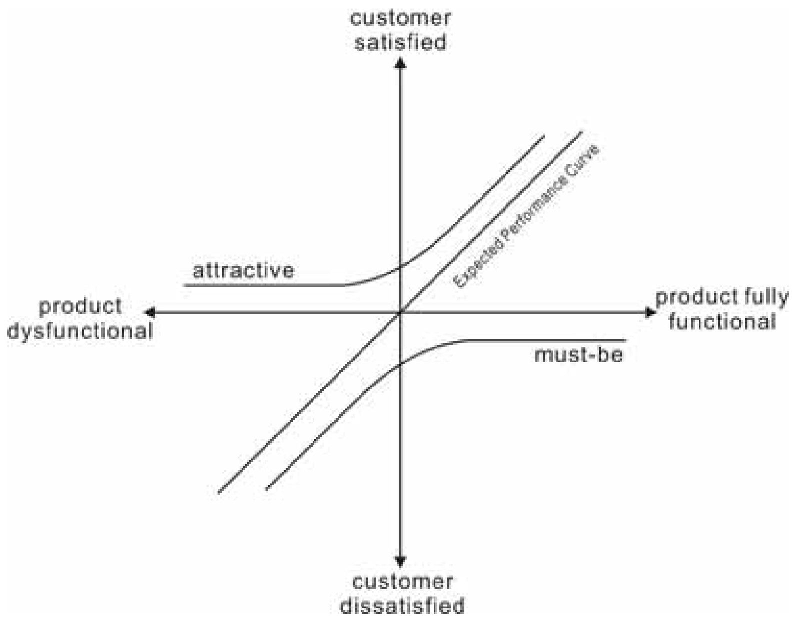


Figure 2-5 The Kano diagram for customer satisfaction (Shiba et al, 1993)

2.3 Product specifications

Product specifications reflect customer needs, and are the result of the requirements of the target market being analyzed and translated into product features sizes and capacities. For example, the customer demands a reduction in the noise of a washing machine, or an increase in the washing capacity. These generalized requirements must be converted into values and units, such as the noise should be less than 50 db, and the maximum laundry capacity shall be 13 kilograms. 50 db and 13 kilograms are definite requirements than can be incorporated into product specifications.

Each product specification should be measurable at any stage of the development process, not just only at the end of the process where the product is designed and built. The specification of a product should be set up early and often checked.

An important step that cannot be neglected during the process of stipulating product specifications is to incorporate lessons learned from competitors. In approximately 500 BC, the Chinese warrior Sun Tzu said, "Know your enemy to know yourself, in a hundred battles you will never peril"(Cleary, 1988). Successful products integrate detailed best-in-class comparative information into the product development process. This information is vital at the following development stages:

- in the front end of the design process for identifying customer needs – to help understand what needs competitors are satisfying
- for improving concept generation – to help start new concepts which may be based on competitors products

- for developing a product – so that the state-of-the-art or exciting design features of the best-in-class products can be emulated or improved upon
- for establishing product specifications (including cost) – to help ensure the competition can be outperformed
- for executing detailed design – and to ensure the best components and suppliers are used

Product teardown is another important method of verifying product specifications, and the main method is the subtract and operate procedure (SOP). SOP is the following five-step procedure aimed at exposing redundant components in an assembly or subassembly through the identification of the true functionality of each component (Lefever and Wood 1996):

- Step 1: Disassemble (subtract) one component of the assembly.
- Step 2: Operate the system through its full range.
- Step 3: Analyze the effect.
- Step 4: Deduce the subfunction of the missing component.
- Step 5: Replace the component and repeat the procedure n times.

2.4 Generating a concept

After identifying a set of customer needs and establishing target product specifications, the designer faces the following questions:

- What existing solution concepts, if any, could be successfully adapted for this application?
- What new concepts might satisfy the established needs and specifications?
- What methods can be used to facilitate the concept generation process?

The concept generation process begins with a set of customer needs and target specifications and results in a set of product concepts from which the team will make a final selection.

A product concept is an approximate description of the technology, working principles, and form of the product. It is a concise description of how the product will satisfy the customer needs. A concept is usually expressed as a sketch or as a rough three-dimensional model and is often accompanied by a brief textual description. The degree to which a product satisfies customers and can be successfully commercialized depends to a large measure on the quality of the underlying concept. A good concept is sometimes poorly implemented in subsequent development phases, but a poor concept can rarely be manipulated to achieve commercial success. Fortunately, concept generation is relatively inexpensive and can be done relatively quickly in comparison to the rest of the development process. The process for concept generation could use follows closely that suggested by Ulrich and Eppinger (1995) while the evaluation process is similar to that used by Ullman (1997). These are shown in Figure 2-6.

The concept generation method can also be presented as a five-step method (see Figure 2-7).

- Step 1: Clarify the problem.
- Step 2: Search externally.
- Step 3: Search internally.
- Step 4: Explore systematically.
- Step 5: Reflect on the solutions and the process.

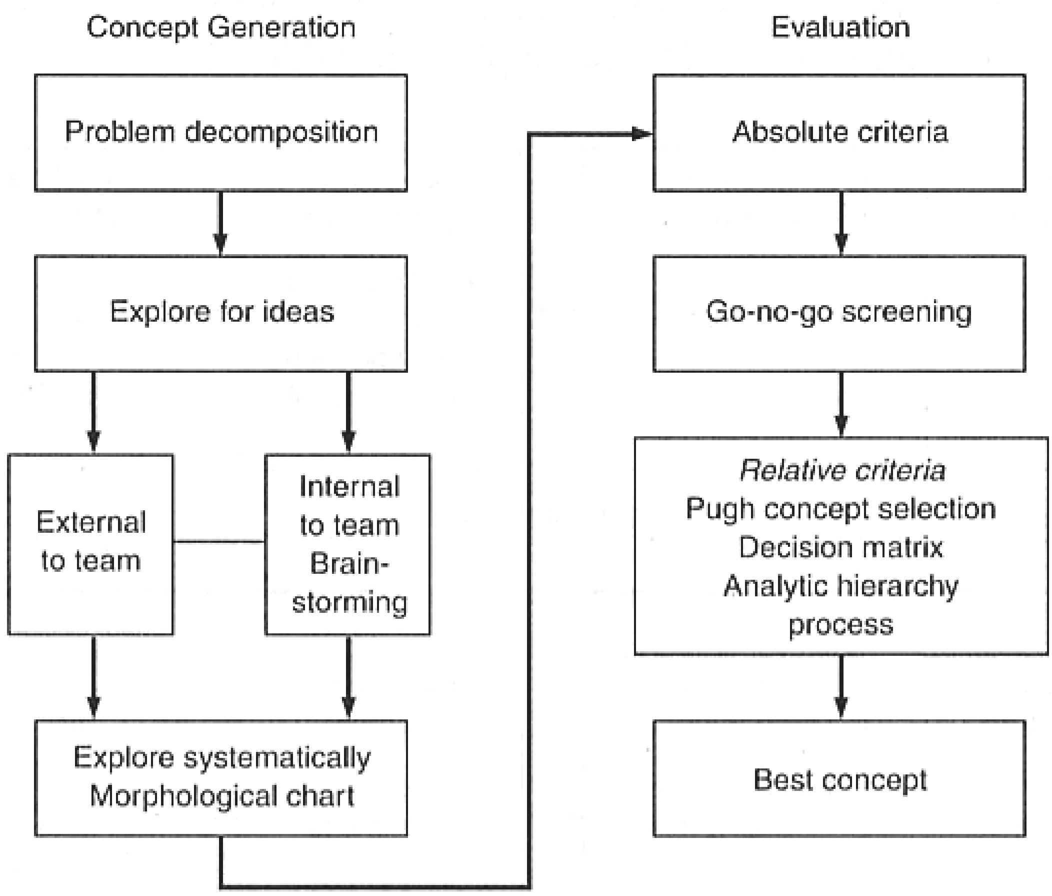


Figure 2-6 Steps that will be discussed in the concept generation and evaluation process (Ullman ,1997)

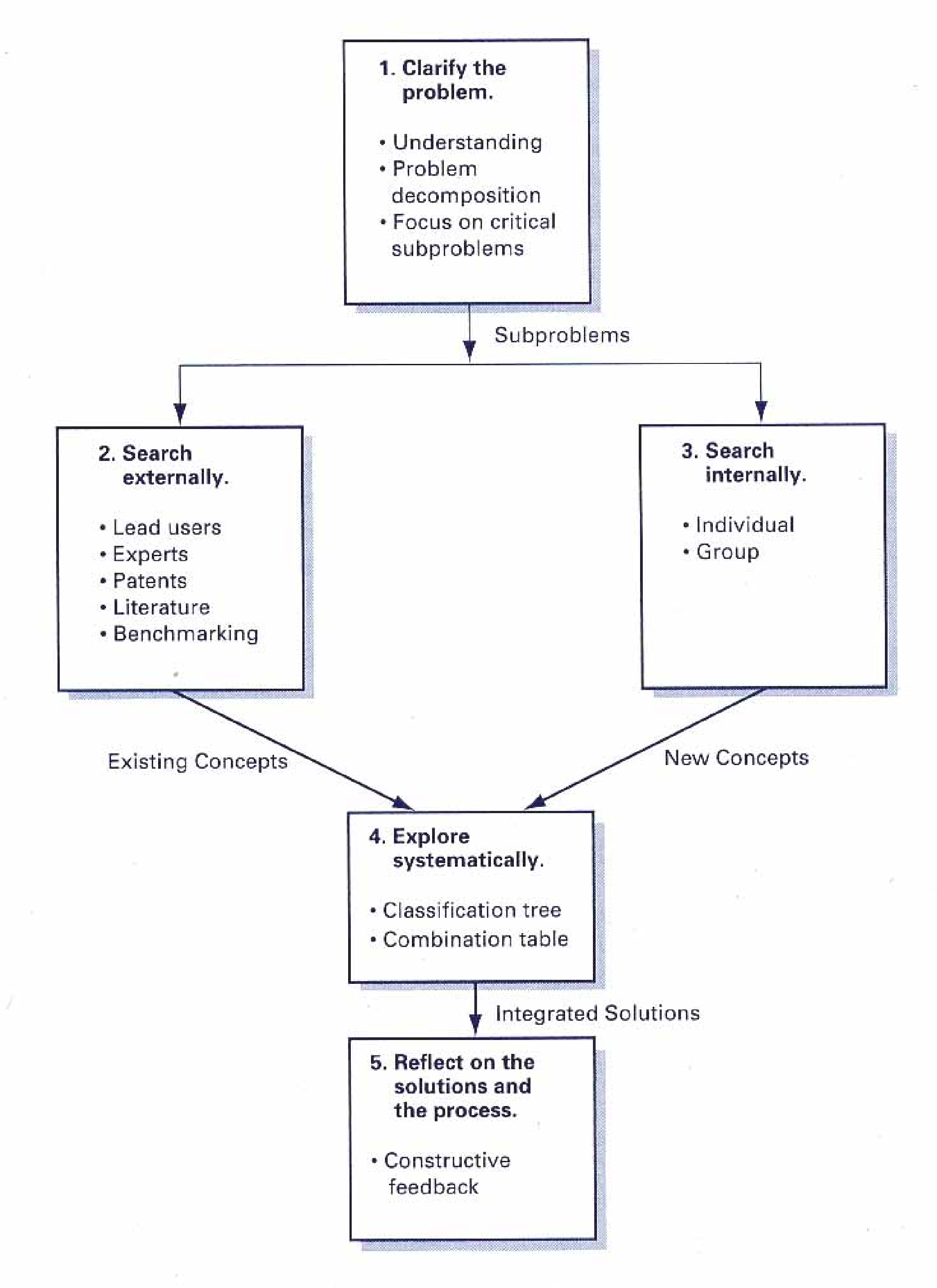


Figure 2-7 The five-step concept generation method (Ulrich & Eppinger, 1995)

2.5 Selecting a concept

To make decisions effectively when selecting a concept, one must carry out two basic steps. The first is to minimize the possibility of misrepresenting a solution principle that may be effective. This oversight often happens when a technology is not in the direct experience of the engineers making the decisions, and so it is not seriously considered. The second step that one must complete to prevent poor decision making is to fully consider the different ramifications of a decision.

Concept selection is the process of evaluating concepts with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts, and selecting one or more concepts for further investigation, testing, or development. The concept selection activity is related to the other activities that make up the concept development phase of the product development process.

While many stages of the development process benefit from unbounded creativity and divergent thinking, concept selection is the process of narrowing the set of concept alternatives under consideration. Although concept selection is a convergent process, it is frequently iterative and may not produce a dominant concept immediately.

Whether or not the concept selection process is explicit, all teams or designers use some method for choosing a particular concept. (Even those teams or designers generating only one concept are using a method: choosing the first concept they think of.) The methods vary in their effectiveness and include the following:

- External decision: Concepts are turned over to the customer, client, or some other external entity for selection.
- Product champion: An influential member of the product development team chooses a concept based on personal preference.
- Intuition: The concept is chosen by its feel. Explicit criteria or trade-offs are not used. The concept just seems better.
- Multi-voting: Each member of the team votes for several concepts. The concept with the most votes is selected.
- Pros and cons: The team lists the strengths and weaknesses of each concept, makes a choice based upon group opinion.
- Prototype and test: The organization builds and tests prototypes of each concept, making a selection based upon test data.
- Decision matrices: The team rates each concept against prespecified selection criteria, which may be weighted.

Successful design is facilitated by structured concept selection. A two stage process was recommended for concept screening and concept scoring. The concept-screening method is based upon the concept selection process presented by Stuart Pugh (1991). Pugh was known to criticize more quantitative methods, such as the concept-scoring method. He cautioned that number can be misleading and can reduce the focus on creativity required to develop better concepts. Concept scoring is similar to a method often called the Kepner-Tregoe method (Kepner and Benjamin B, 1965). It is described, along with other techniques for problem identification and solution, in their text. Concept scoring uses weighted selection criteria and a finer rating scale. Concept scoring may be skipped if concept screening produces a dominant concept. Both screening and scoring use a matrix as the basis of a six-step selection process. The six steps are:

- Step 1: Prepare the selection matrix.
- Step 2: Rate the concepts.
- Step 3: Rank the concepts.
- Step 4: Combine and improve the concepts.
- Step 5: Select one or more concepts.
- Step 6: Reflect on the results and the process.

2.6 Developing the concept

Developing a concept should include two directions. One is developing the concept for manufacture and assembly, the other is developing the concept for the environment. These two directions could be simultaneously considered for the concept development.

Design for manufacture (DFM) primarily entails minimizing part count, but also making attachment directions. Minimizing part count and making attachment directions could effectively reduce time for assembly or decomposition and could economize on resource consumption. For example, the prototype of a traffic cone used in this project included over ten parts; if the part count can be minimized by incorporating multiple functions into single or simple parts, then a lot of time for fabrication may be saved. Design for assembly (DFA) entails making attachment directions and, methods simpler, for example, making a part easy to attach by using snap fits instead of machine screws. Design for assembly involves the application of attachment time and complexity models, whether they are basic rules, tables based on simplified time studies, or full-time and motion industrial engineering studies.

Design for manufacture and assembly is important because it has three beneficial impacts. First and foremost, it reduces part count, thereby reducing cost. If a design is easier to produce and assemble, it can be done in less time, and so it is cheaper. Finally, design for manufacture and assembly also generally increases the quality of a design and for the same reasons it also increases reliability (Branan 1991; Barkan and Hinckley 1993). For product development purposes, an effective breakdown is to consider costs according to physical manufacturing processes. Each of these can then be costed and different processes considered. As shown in Figure 2-8, manufacturing cost may be broken down into piece part costs, which covers the costs of both parts made and bought from suppliers, assembly costs, and overhead rate, which is the cost of supporting direct production of parts and assembly.

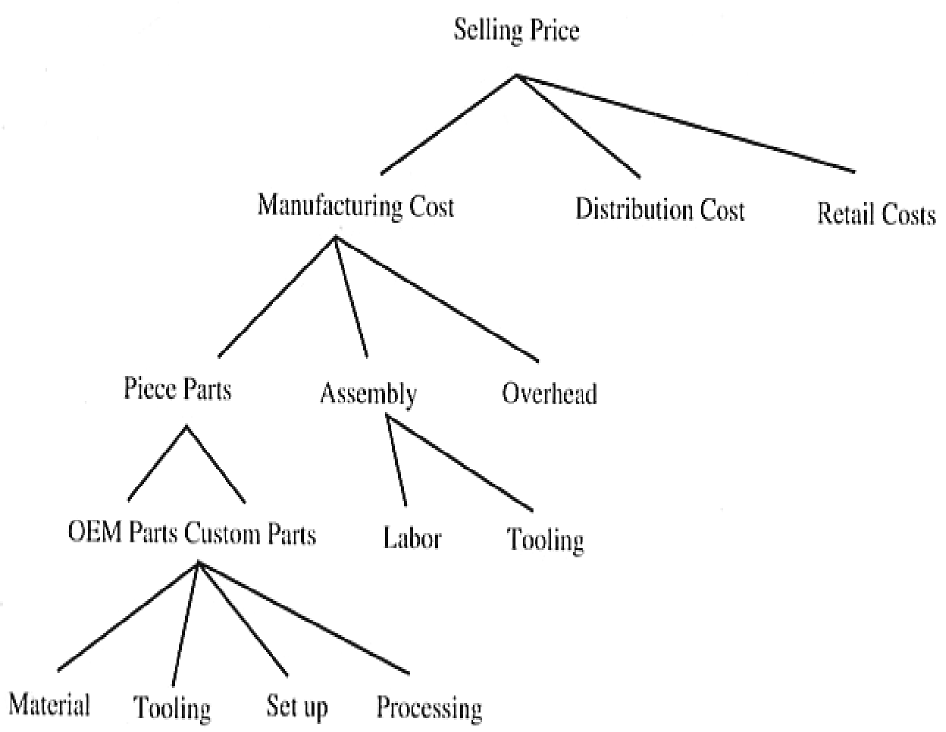


Figure 2-8 Production cost analysis breakdown

A growing concern in the latter part of the twentieth century has been the tremendous impact humans now have on the environment. Society generates and consumes such a large fraction of the Earth's resources that industries or organisations must consider environmental impact during technical decision making. A growth area for society, engineering, and design is to simply maintain the standard of technological living that is now enjoyed into this century, but at a sustainable level of low environmental impact. Design for the environment (DFE) is a product design approach for reducing the impact of products on the environment.

DFE is an important activity for a designer or team because environmental damage is, as are most things, greatly influenced in the early design phases. Just as with production cost, a reasonable heuristic is that 80% of the environmental damage of a product is established after 20% of the design activity is complete. When a useful life of product is over, the impending scrapped product will face one of three things happens to its components, they are either disposed of, reused, or recycled. To develop a more complete analysis, a full life cycle assessment of a product is needed.

The issues of energy, pollution, and resource conservation are aspects of design where we must continually pay attention and there is currently an emphasis and concern for more sustainable processing of raw materials for products. Tools have been developed to help redesign a product to improve its environmental impact. There are several basic design approaches:

- to minimize material usage
- for disassembly

- for recycling
- for remanufacturing
- to minimize hazardous materials
- for energy efficiency
- to regulations and standards

Understanding the environmental impact of a product and intervening as a designer or team to mitigate effects is a responsibility that must now be adopted. Legislative and consumer demands will only increase in this area. Developing the concept for manufacture and assembly was combined with the cost analysis to reduce spending. Developing the concept for the environment is becoming a social responsibility of an organization or enterprise, although it maybe not reduce cost but it can still be converted into the intangible assets of the enterprise – raising the goodwill.

2.7 Final design

The final design should be conducted when the production drawings are complete and ready for release to manufacturing. In most cases qualification prototype testing will have been completed. The purpose of the final design is to compare the design against the most updated version of the product design specification (PDS) and a design review checklist, and to decide whether the design is ready for production.

Since this is the last review before design release, a complete complement of personnel should be in attendance. This would include design specialists not associated with the project to constructively review that the design meets all requirements of the PDS. Other experts review the design for reliability and safety, quality assurance, field service engineering, and purchasing. Marketing people or the customer's representatives will be present. Manufacturing personnel will be in strong attendance, especially plant operating management responsible for producing the design, and DFM experts. Other experts who might be called in, depending upon circumstances, are representatives from legal, patents, human factors, or R & D. Supplier representation is often desirable. The intent is to have a group comprised of people with different expertise, interests, and agendas. The chairperson of the final design will be an important corporate official like the VP of engineering, the director of product development, or an experienced engineering manager, depending on the importance of the product. An effective design consists of three elements (Stater-Black, K. & Iverson, N. 1994).

(i) input documents

The input for the final design consists of documents such as the PDS, the quality function deployment (QFD) analysis key technical analyses like finite element analysis (FEA) and computational fluid dynamics (CFD), failure modes and effects analysis (FMEA), the quality plan, including robustness analysis, the results of the qualification tests, the detail and assembly drawings, and the product specifications, and cost projections. This documentation can be voluminous and it is not all covered in the final design. Important elements will have been reviewed previously and they will be certified at the final design. Another important input to the meeting is the selection of the people who will the review. They must be authorized to make decisions about the design and have the ability and responsibility to take corrective action.

(ii) an effective meeting process

The final design meeting should be formally structured with a well-planned agenda. The final design is more of an audit in contrast to the earlier reviews, which are more multifunctional problem-solving sessions. The meeting is structured so it results in a documented assessment of the design. The final design uses a checklist of items that need to be considered. Each item is discussed whether it passes the final design. The drawings, simulations, test results, FMEAs, etc., are used to support the evaluation. Sometimes a 1-5 scale is used to rate each requirement, but in a final design an "up or down" decision needs to be made. Any items that do not pass the review are tagged as action items and with the name of the responsible individual.

(iii) an appropriate output

The output from the final design is a decision as to whether the product is ready to be released to the manufacturing department. Sometimes the decision to proceed is tentative, with several open issues that need to be resolved, but in the judgment of management changes can be made before product launch.

Chapter 3

Experimental

3. Experimental

3.1 Introduction

The appearance of a traffic cone suggests quite a simple design, but the theoretical foundation on which the design is based is extensive. However, the aim of this project is to develop further discussion and application using a knowledge of dynamics and mechanics of materials for the redesign of a traffic cone. The prototype traffic cone developed here includes many parameters and variables, for example the rigidity of the cone body, elasticity coefficient of the rubber strips, stiffness of the rubber base and so on. All these parameters directly or indirectly influence the resultant design of the traffic cone. In order to establish a model and carry out analysis, obtaining relevant data to feed into the model is very important. The following experiments are designed to gather important data, and these values could be the basic elements for further analysis and simulation in the future.

All experiments in this stage do not consider any deformation of the cone body. The cone body is considered to be a rigidly shelled object to simplify the complex analysis. Therefore, all the resultant analysis and simulation will be focused on the rubber base, the rubber strips and their influence upon the whole of the traffic cone.

3.2 Description of the tested prototype

The traffic cone may be divided into four parts. The estimated weight of the traffic cone is about 6.5 kg. A prototype of a redesigned traffic cone is shown in the figure 3-1. The four parts are individually described below:

3.2.1 The cone body

The cone body consists of a hollow shell, moulded from polyethylene. It is a symmetrical shape. The thickness of the shell cone is uniformly increased from top to bottom, from about 2.53mm to about 4.15mm. The height of the cone is about 855mm and its weight is 1.665kg. The inside diameter of the bottom of the cone is 210mm, and the outside diameter of the top of the cone is about 44mm. As shown in Figure 3-1(a).

3.2.2 The rubber base

The base is of square shape, as shown in Figure 3-1(b). It is made of rubber, and has a thickness of about 26.30mm, and a weight of 4.1 kg.

3.2.3 The rubber strips

The rubber strips are used for connecting the cone to the base. The rubber strips can support the cone and can make the cone stand up. There are four rubber strips in total and they are fixed individually onto the base and the cone. The thickness of each rubber strip is about 6.60mm and their width is about 29mm but the effective length of the rubber strip is an experimental variable. The weight of a single strip is about 37g. An example is shown in Figure 3-1(c).

3.2.4 Other components

Other components include screws, iron plates, nuts and cork. The sum weight of these components is about 0.6kg.

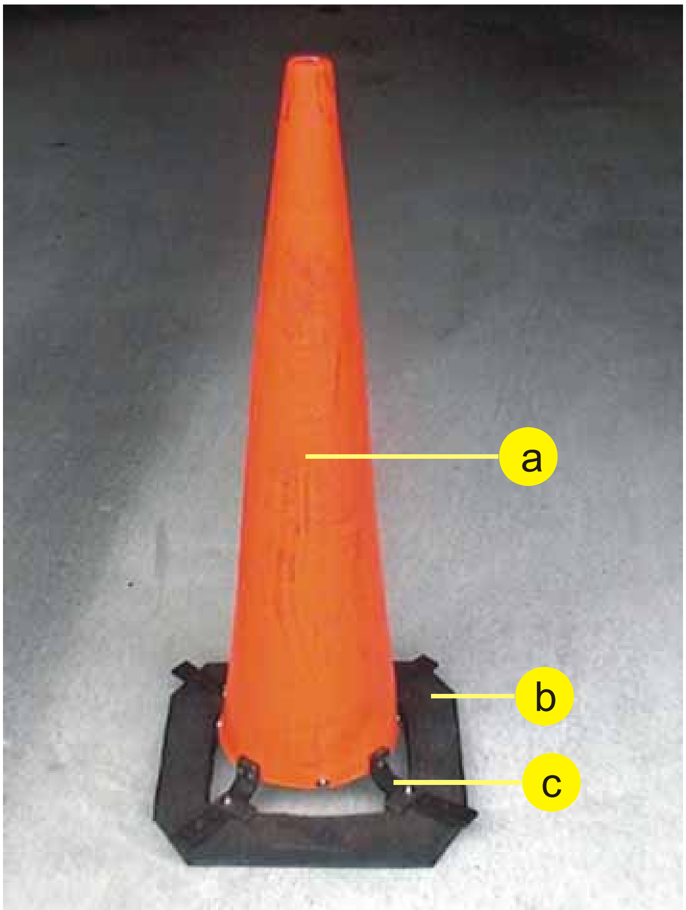


Figure 3-1 (a) The cone body (b) The rubber base (c) The rubber strip

3.3 Density measurements

3.3.1 Purpose

The mass and volume of the rubber base and rubber strips were measured, in order to calculate the density of the materials. This data was a required input for future computer simulations. Two different methods were used to determine the density, to reduce any errors of measurement.

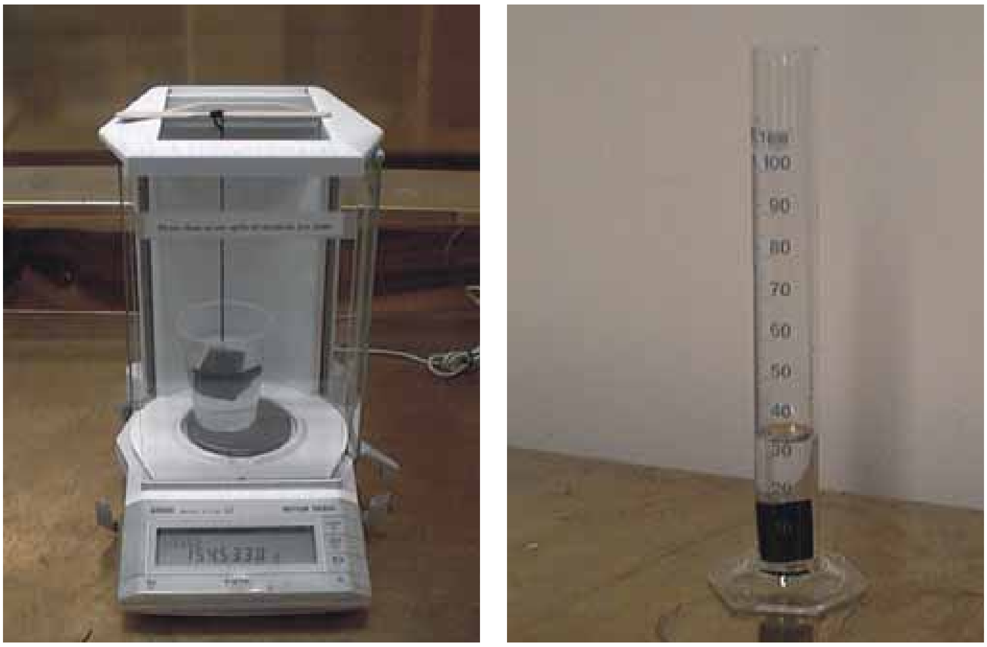
3.3.2 Method

(1) Small portions of material were taken from the rubber base and a rubber strip, and these portions were weighed on a scale.

(2) Method one, Archimedes' principle was used to determine the volume of the objects using their buoyancy. This is shown in Figure 3-2(a).

(3) Method two, each object was placed into a measuring cylinder partially filled with water, the change in water level corresponded to the volume of the object. As shown in Figure 3-2(b).

(4) The values of volume and mass of each portion were then used to calculate the material densities, using the equation density = mass / volume.



(a) (b)

Figure 3-2 The rubber's volume was measured by (a) Archimedes' principle with buoyancy (b) direct observation method

3.3.3 Experimental data

Table 3-1 shows the material densities calculated using both experimental methods. This data was used as an input into the computer simulation.

Table 3-1 Experimentally determined rubber densities

Method	Rubber Base			Rubber Strip		
	M(g)	V(cm^3)	D(g/cm^3)	M(g)	V(cm^3)	D(g/cm^3)
Buoyancy	32.34	15.78	2.05	17.37	11.3	1.54
Observation	32.35	16.5	1.96	17.38	12.9	1.35
	Average density		2.01	Average density		1.45
Where M is mass, V is volume and D is density						

3.4 Impact test I

3.4.1 Purpose

The purpose of this experiment was to gather data on the minimum impact that makes the traffic cone topple over. A pre-produced cement ball (the total weight of the cement ball is about 7.4kg) was used to strike the traffic cone, and the swing distance of the cement ball from the traffic cone was recorded.

3.4.2 Method

(1) One end of the plastic rope was fixed 2150mm above the ground.

(2) The cement ball was tied to the other end of the rope, so that the ball was suspended in the air. The vertical height from the ground to the centre of the ball was controlled and recorded.

(3) With the suspended cement ball in a static state, the traffic cone was placed so that the surface of the cone touched the cement ball (Figure 3-3, a).

(4) The cement ball was then swung back to a measured height and released to strike the traffic cone. The horizontal distance from the centre of the ball to the point of impact with the cone was recorded (Figure 3-3, b and c).

(5) The suspended height of the cement ball was varied and steps (3) and (4) were repeated until the minimum horizontal distance that resulted in the cone falling over was determined.

(b)

(a) (c)

Figure 3-3 (a) The cement ball touching the surface of the cone (b) Raising the cement ball to the release point (c) The cone toppling over

3.4.3 Experimental data

Table 3-2 shows the minimum impact energy required to topple the cone with different vertical heights to the centre of the cement ball. Figure 3-4 illustrates the process of the impact test.

Table 3-2 Results for the minimum impact energy ΔU by impact testing

l=2150mm Weight of cement ball=7.471kg					unit:mm
l_0	x_0	h_1	h_2	$\Delta h=h_2-h_1$	ΔU(joule)
1735	897	415	664.8	249.8	18.1
1665	1037	485	847.3	362.3	26.3
1595	1292	555	1214.7	659.7	47.8
1565	1322	585	1312.4	727.4	52.8

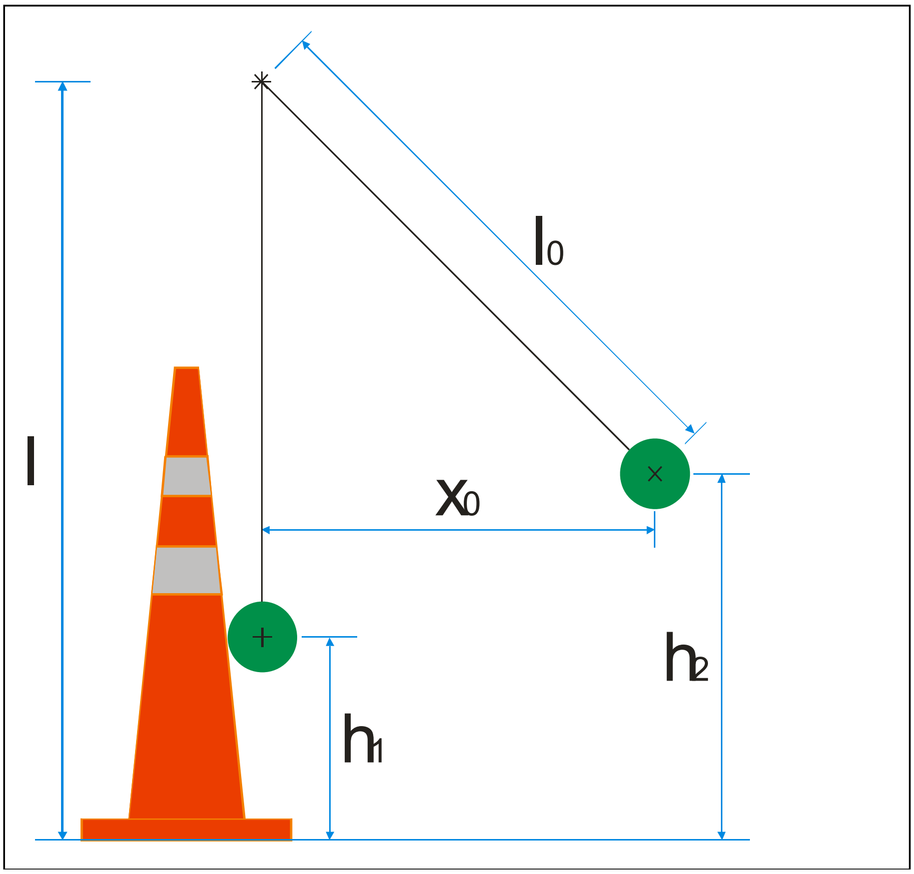


Figure 3-4 A schematic drawing of the impact testing arrangement

3.5 Impact test II

3.5.1 Purpose

While processing data from impact test I, it was found that the supporting length of the rubber strips may have affected the minimum impact energy required to topple the traffic cone. Therefore, the purpose of this experiment was to determine how different lengths of the rubber strip affect the impact resistance of the traffic cone, using the same testing procedure as with impact test I.

3.5.2 Method

In order to keep the cone body standing vertically upright it was necessary to position the holes on each of the three rubber strips differently. The free bending lengths of the rubber strips were therefore different, even when fixed on corresponding holes. The average free length of rubber strip was employed at this stage to simplify analysis. The average free length for each hole was 33.75mm, 58.50mm and 83.50mm respectively.

(1) Each rubber strip may be fixed in one of three different positions, using holes punched into the rubber. (Figure 3-5, b).
(2) The first hole of each rubber strip was used to fix the strips to the rubber base.
(3) The impact test was performed, using the same method as for impact test 1.
(4) The arrangement was changed to the next hole on the rubber strip and step (3) was repeated.
(5) The data from the impact tests for the three different hole positions was recorded as Table 3-3.

(a)

(b)

(c)

(d)

Figure 3-5 (a) The four rubber strips with the cone (b) one of the strips with its three mounting positions (c) and (d) are commercial products and used on roads. currently the weight is 4.4 kg and 6.3 kg respectively

3.5.3 Experimental data

This experiment is similar to impact test I (section 3.4), with the varied connective length of rubber strips between the cone and base being the only test difference. The experimental data is recorded in Table 3-3, and also shown in Figure 3-6. Two commercial traffic cones of traditional design were also tested in this experiment in order to compare the differences between them. The resultant of data is also recorded in Table 3-3. 1St, 2nd and 3rd refer to the prototype design with supporting strips of different length, A and B refer to commercial products.

Table 3-3 Impact test data

Item	l=2150mm Weight of cement ball=7.471kg unit:mm					
	l_0	x_0	h_1	h_2	$\Delta h=h_2-h_1$	ΔU(joule)
1st (free length 33.75mm)	1735	897	415	664.8	249.8	18.1
	1665	1037	485	847.3	362.3	26.3
	1595	1292	555	1214.7	659.71	47.8
	1565	1322	585	1312.4	727.4	52.8
2nd (free length 58.50mm)	1741	1142	410	836.8	426.8	30.9
	1651	1252	500	1074.7	574.7	41.7
	1591	1342	560	1296.4	736.4	53.4
	1556	1357	595	1389.6	794.6	57.6
3rd (free length 83.50mm)	1740	1172	410	863.9	453.9	32.9
	1645	1247	505	1077.1	572.1	41.5
	1597	1302	553	1225.2	672.2	48.7
	1557	1327	593	1335.5	742.5	53.9
A (4.4kg)	1740	635	410	530.0	120.0	8.7
	1660	620	490	610.1	120.1	8.7
	1600	698	550	710.2	160.2	11.7
	1558	724	592	770.4	178.4	13.0
B (6.3kg)	1740	729	410	570.0	160.0	11.7
	1660	732	490	660.1	170.1	12.4
	1600	775	550	750.2	200.2	14.6
	1558	795	592	810.0	218.0	15.9

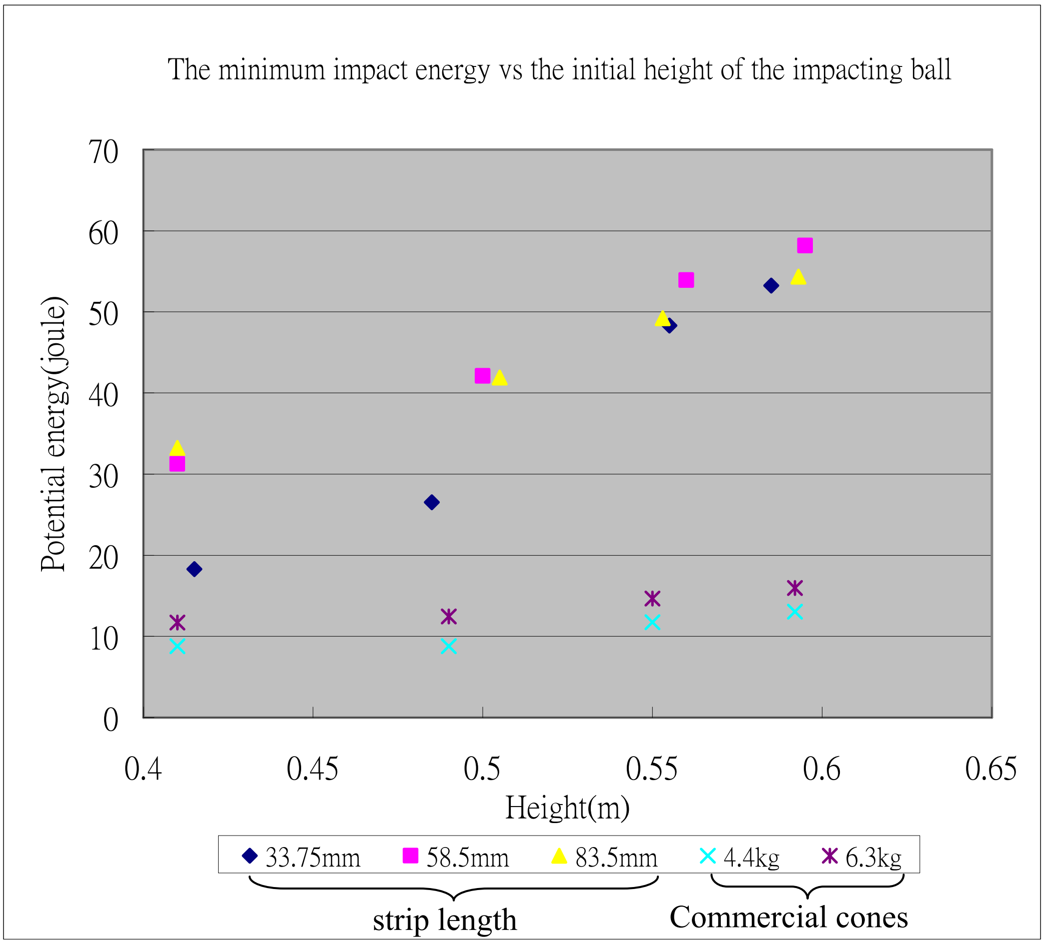


Figure 3-6 A comparison of the minimum energy to cause toppling for different strip lengths and commercial cones

3.6 Tensile test

3.6.1 Purpose

The aim of this testing was to determine the elastic modulus of the rubber strip. The experiments followed the American Society for Testing Material (ASTM D412-989) standard in which a dumbbell shaped specimen is cut and tensile tested. The relationship between the normal force and the extension of the specimen was obtained and the elastic modulus of the specimen derived.

3.6.2 Method

(1) Several dumbbell specimens of the rubber strip material were cut using a standard die of the dimensions listed in the ASTM standard. (Figure 3-7, a).

(2) A uniform rate of crosshead movement was set. Test extension rates were 500mm/min, 100mm/min, 10mm/min.

(3) Both ends of specimen were clamped to give the required grip separation and the test was then started (Figure 3-7, b).

(4) Step (3) was repeated with a changed extension rate.

(5) Test data of applied force and extension was recorded by the testing machine computer. The relevant force-extension curves with different cross-head speeds are shown as Figure 3-8.

(a)

(b)

Figure 3-7 (a) Rubber tensile test specimens (b) The Lloyd LR 100K tensile machine used in this work.

3.6.3 Experimental data

Figure 3-8 shows the data relating specimen extension and applied force using different rates of crosshead movement. The curves shown were obtained at the testing rates of 500, 100 and 10mm/min.

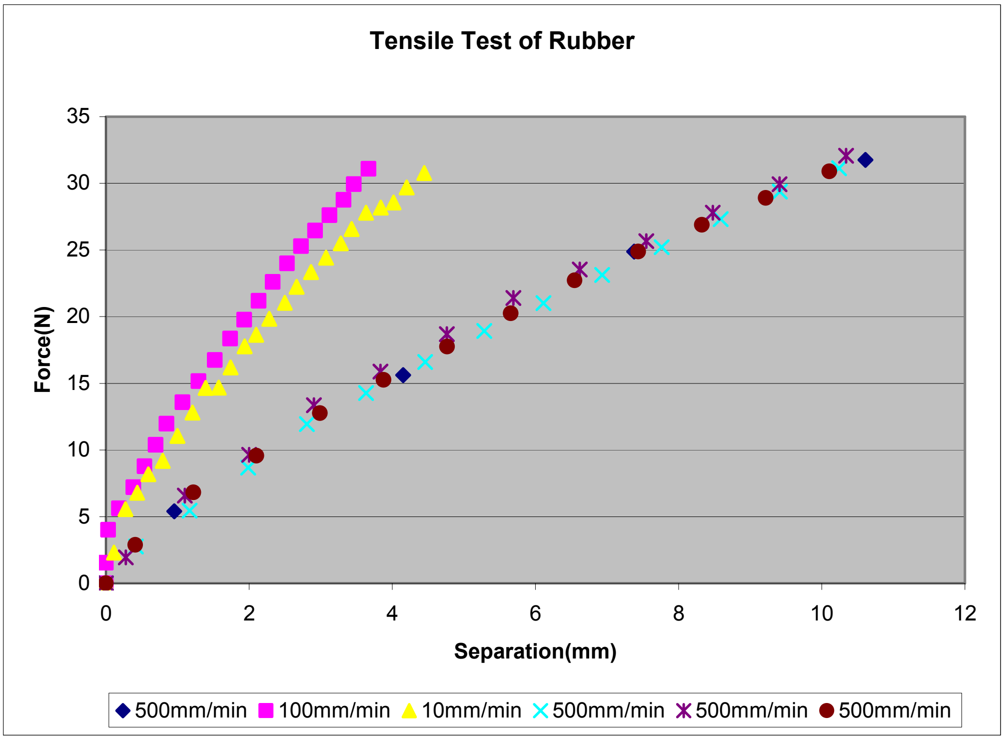


Figure 3-8 The relationship between the applied force and separation obtained at different extension rates

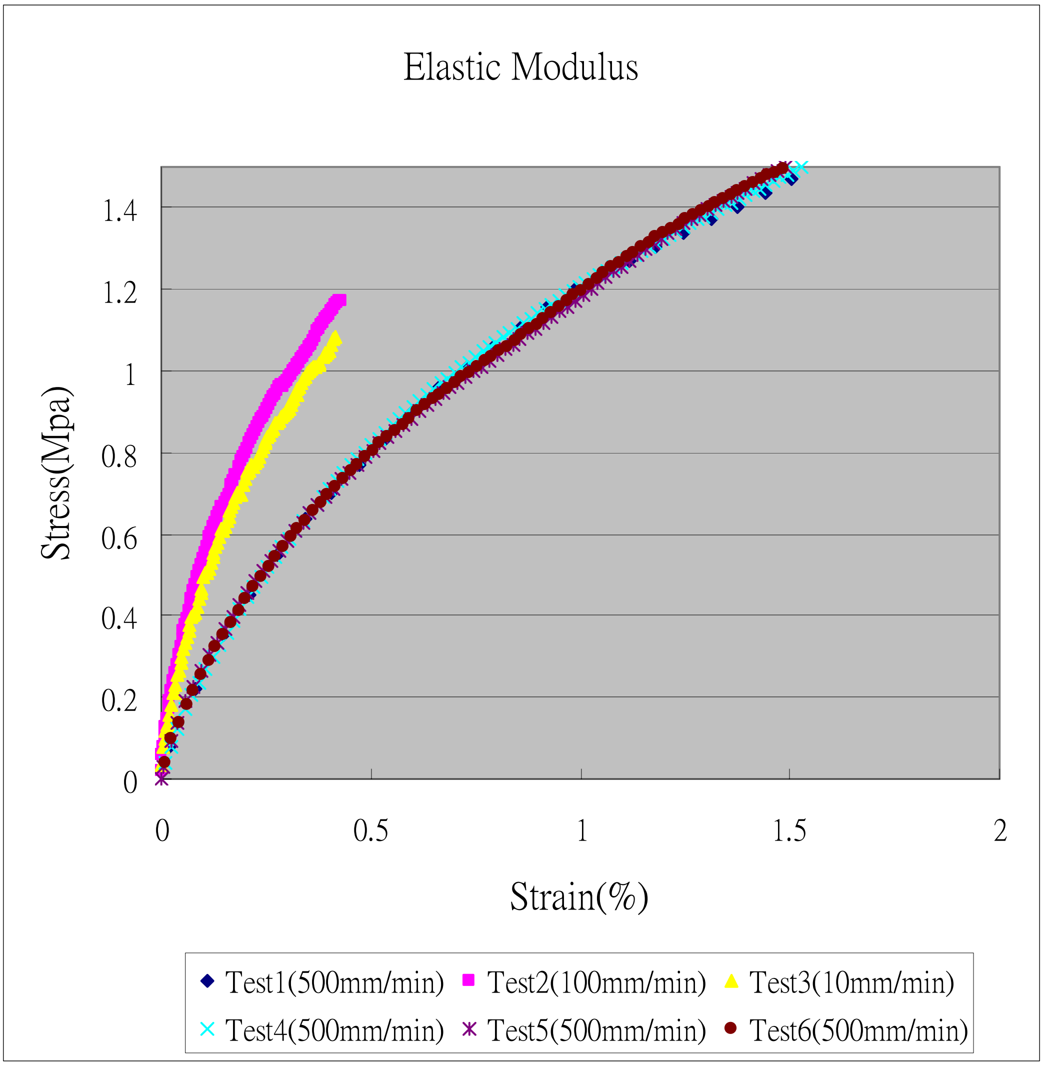


Figure 3-9 The stress-strain behaviour at different extension rates

3.7 Drooping of rubber base due to gravity

3.7.1 Purpose

The flexibility of the rubber base is such that when unsupported, it will droop significantly due to gravity. For the purposes of computer simulation, the stiffness of the rubber base must be known although measuring this value is difficult due to the awkward shape of the base. The following experimental method was developed to measure this parameter.

3.7.2 Method

(1) The rubber base was fixed to a desk using the two or three C-clamps, in such a way that one edge of the base was unsupported and allowed to droop.

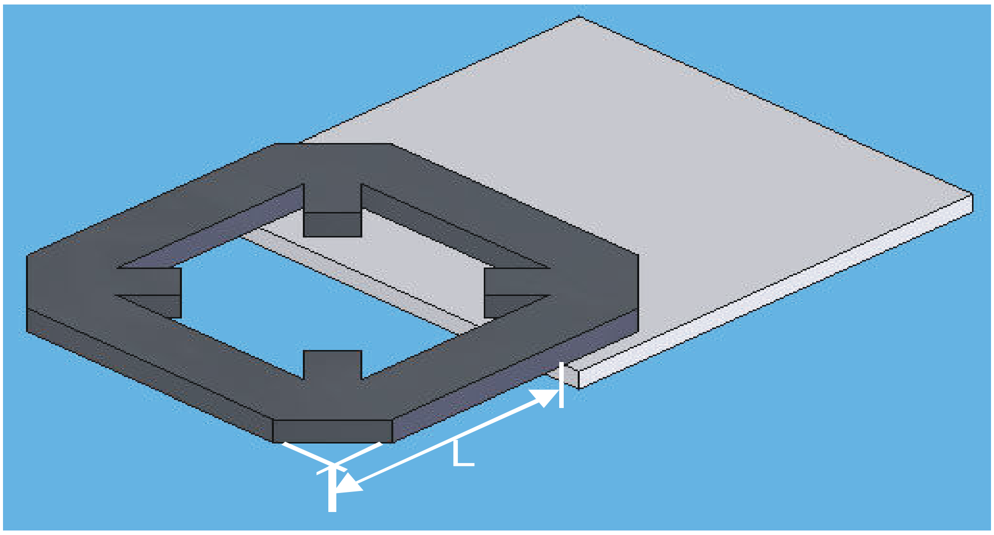
(2) The length of the rubber base protruding from the edge of the desk was measured, as illustrated in Figure 3-10 (a).

(3) Five points were marked on the forward part of the rubber base. There are shown in Figure 3-10 (b).

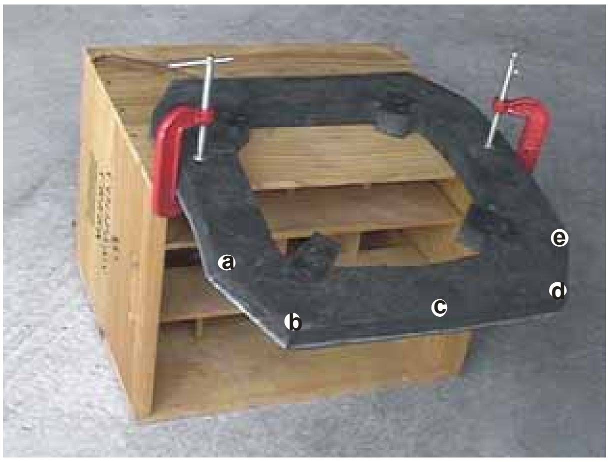
(4) The vertical distance from each of these points to the top of the rubber base was measured. It is shown as Figure 3-10 (c).

(5) Steps (2) to (4) were repeated using a range of unsupported lengths of the rubber base.

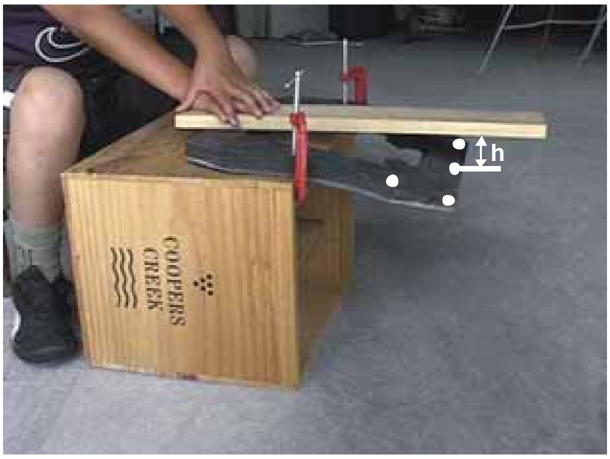
Table 3-4 Shows the relationship between the vertical height of each marked position of the base edge and different protruding lengths of the rubber base.



(a)



(b)



(c)

Figure 3-10 (a) L is the length of the rubber base protruding from the edge of the desk. (b) Five points are marked on the rubber base. (c) Measuring the vertical distance to these points.

3.7.3 Experimental data

Table 3-4 The relationship between the unsupported length of the rubber base to the drooping displacement

L(mm)	h_a(mm)	h_b(mm)	h_c(mm)	h_d(mm)	h_e(mm)
	Measurement	Measurement	Measurement	Measurement	Measurement
170	15	20	24	20	15
190	23	31	33	31	23
210	29	41	42	41	30
230	42	57	59	57	43
250	58	76	80	76	58
270	70	92	94	92	70
290	82	105	109	106	84
310	102	127	129	127	102

Where L is the protruded length of the rubber base, and h_a, h_b, h_c, h_d and h_e are the vertical distances to the different points.

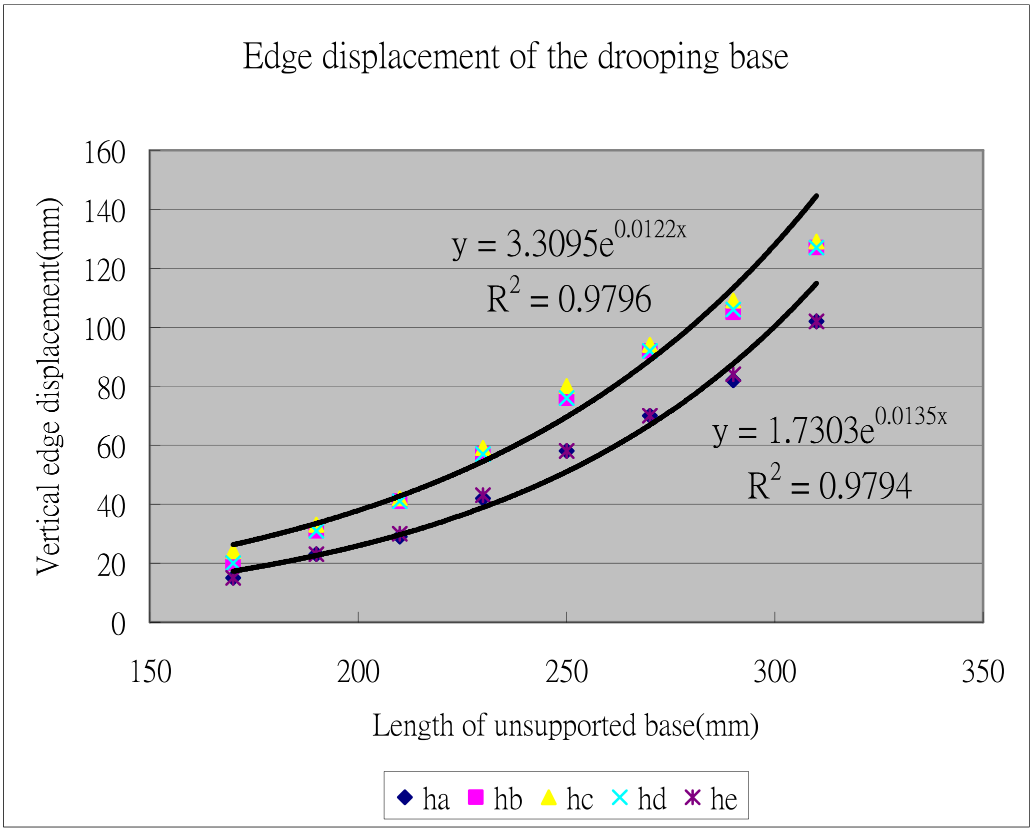


Figure 3-11 Graph showing the magnitude of base droop due to gravity

3.8 Drooping of rubber strips due to gravity

3.8.1 Purpose

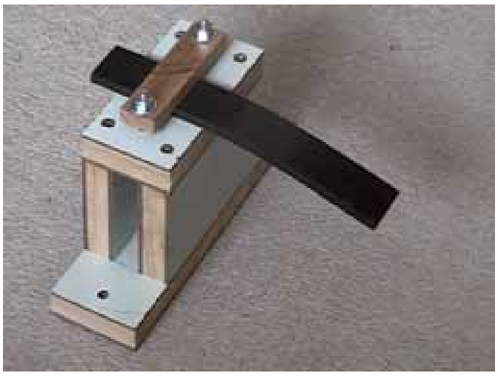
This method is similar to that used to determine the drooping of the rubber base due to gravity (section 3.7). As the shape of a rubber strip is relatively simple, the mechanical properties may be easily figured out from experiments. Therefore, the purpose of this experiment is to determine the stiffness and bending modulus of the rubber strips for use in computer simulation.

3.8.2 Method

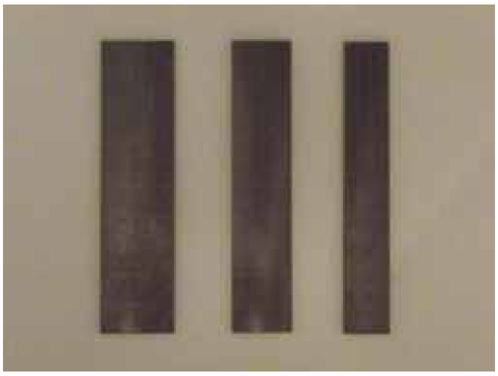
(1) A rubber strip of width 30mm was clamped using a preproduced clamping apparatus, as shown in Figure3-12(a)

(2) The unsupported length of rubber strip and the end deflection of the strip were determined.

(3) Step (1) and (2) were repeated with strips of 40mm and 50mm width.



(a)



(b)

Figure 3-12 (a) Rubber strip held in the clamping apparatus (b) Three test specimens of width 50mm, 40mm and 30mm

3.8.3 Experimental data

Table 3-5 The relationship between the unsupported length and end deflection with different width of rubber strip

Unsupported Length(m)	Unsupported Length^4(m^4)	Deflection(m)			Unsupported force(N)		
		W30 (54g)	W40 (71g)	W50 (89g)	W30	W40	W50
0.08	0.00004096	0.007	0.004	0.006	0.2130	0.2807	0.3519
0.10	0.0001	0.0155	0.011	0.012	0.2662	0.3509	0.4398
0.12	0.00020736	0.029	0.021	0.022	0.3194	0.4211	0.5278
0.14	0.00038416	0.038	0.037	0.037	0.3727	0.4912	0.6158
0.16	0.00065536	0.068	0.063	0.062	0.4259	0.5614	0.7038

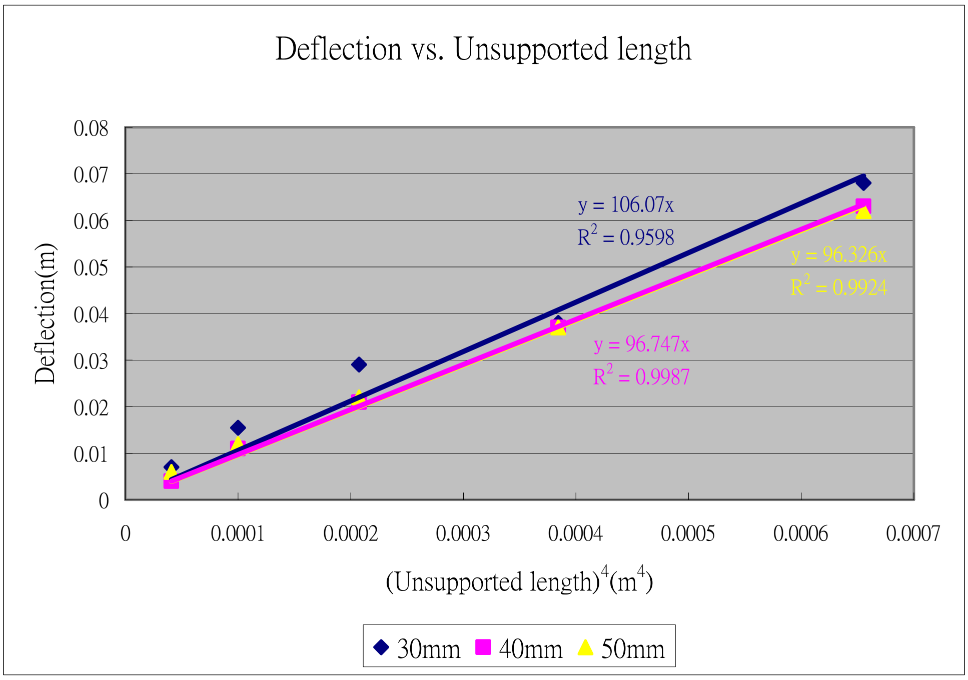


Figure 3-13 Graph of deflection versus unsupported length

3.9 Testing the rubber base with an upward force

3.9.1 Purpose

The rubber base plays a key role in resisting the toppling of the traffic cone, for when the rubber base is bent by an external force, it simultaneously produces an internal force to recover from its deformation. The magnitude of this internal force will influence the traffic cone's response to the application of an external force. Therefore, the purpose of this experiment is to determine the relationship between the deformation of the rubber base and the corresponding internal force.

3.9.2 Method

(1) Apparatus was designed to keep the external applied force perpendicular with the ground even when the rubber base was bent.

(2) The rubber base was placed on the platform of the apparatus. A thin and light plastic board was fixed to an edge face of the rubber base to be used for lifting. The other end of the base was clamped by C-clamps (Figure 3-14, a and b).

(3) One end of the plastic rope was tied to the plastic board. The rope goes around a bearing that functions as a pulley. A counterweight was attached to the other end of the rope.

(4) The weight of the counterpoise was progressively increased, and the bending degree of the rubber base was recorded.

(5) The above steps were repeated without clamps (Figure 3-14, c and d).

(6) The above tests were repeated three times.

(a)

(b)

(c)

(d)

Figure 3-14 Images (a)(b)(c) and (d) are different views of the lifting test, apparatus(a) and (b) with C-clamp, (c) and (d) without clamp

3.9.3 Experimental data

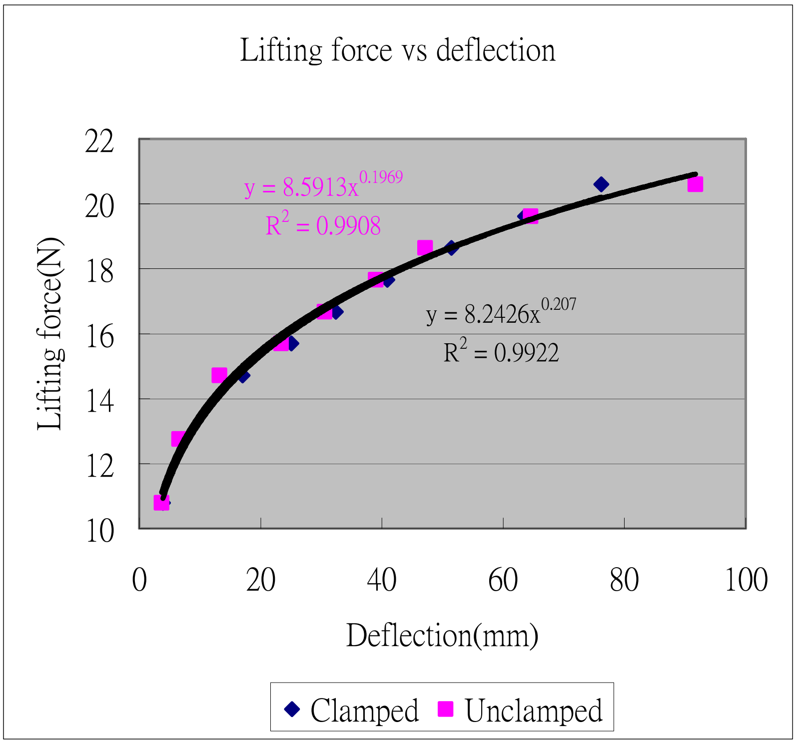
Table 3-6 and Table 3-7 show the relationship between the lifting force and the displacement of the base.

Table 3-6 Lifting test clamped base.

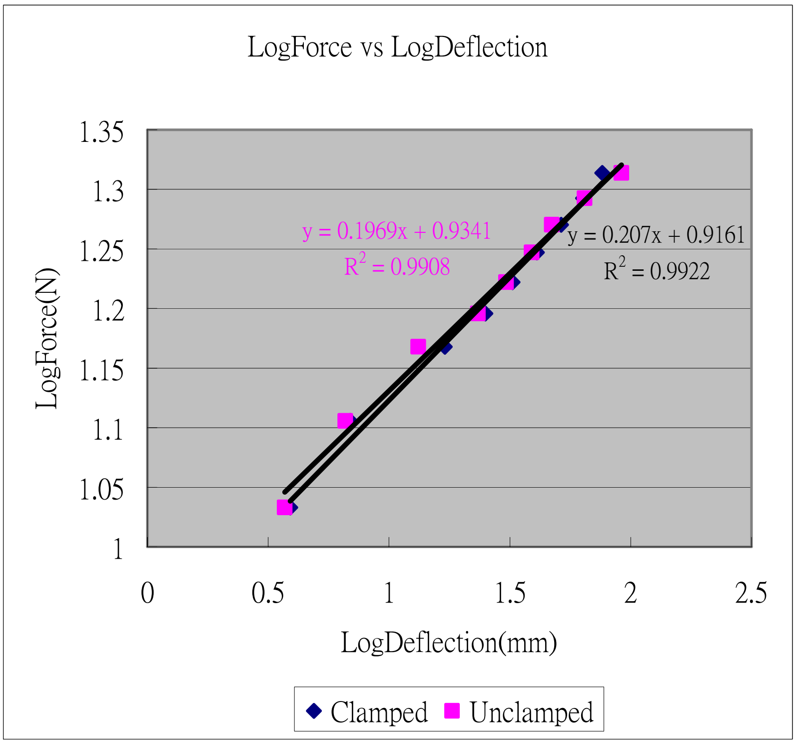
Clamped Base		Test1	Test2	Test3	Average
Counterpoise (kg)	Force (N)	V_{base} (mm)	V_{base} (mm)	V_{base} (mm)	V_{base} (mm)
1.1	10.791	3.3	3.7	4.7	3.90
1.3	12.753	6.2	6.6	7.9	6.90
1.5	14.715	16.8	17.1	17.2	17.03
1.6	15.696	26.1	24.4	24.7	25.07
1.7	16.677	33.1	31.9	32.2	32.40
1.8	17.658	40.1	40.5	42.1	40.90
1.9	18.639	51.8	48.9	53.7	51.47
2.0	19.620	65.8	59.4	65.6	63.60
2.1	20.601	76.1	76.1	76.4	76.20

Table 3-7 Lifting test unclamped base.

Unclamped Base		Test1	Test2	Test3	Average
Counterpoise (kg)	Force (N)	V_{base} (mm)	V_{base} (mm)	V_{base} (mm)	V_{base} (mm)
1.1	10.791	3.7	3.8	3.6	3.70
1.3	12.753	6.5	7.0	6.3	6.60
1.5	14.715	13.3	13.8	12.5	13.20
1.6	15.696	22.3	23.8	24.0	23.37
1.7	16.677	29.4	32.6	29.7	30.57
1.8	17.658	38.8	40.6	37.6	39.00
1.9	18.639	45.8	49.8	45.9	47.17
2.0	19.620	66.0	66.8	60.8	64.53
2.1	20.601	83.8	100.8	90.6	91.73



(a)



(b)

Figure 3-15 The lifting force against deflection

3.10 The degree of cone body and rubber base slope due to an applied external force

3.10.1 Purpose

Because each rubber strip was joined to the cone body and the rubber base at the same time, the application of an external force will cause a progressive sloping movement of the cone body, and then bending of the rubber base. The purpose of this test is to obtain data for the relationship between a varied external force and the cone movement, including both the conical part and the rubber base.

3.10.2 Method

(1) One end of a plastic rope was fixed to the surface of the cone body. The vertical height from the top of the rubber base to the attachment point was 401mm. The other end of the plastic rope was passed around a bearing acting as a pulley and attached to a counterweight (Figure 3-16, a).

(2) The height of the T-support was adjusted to keep the applied force parallel with the ground (Figure 3-16, b).

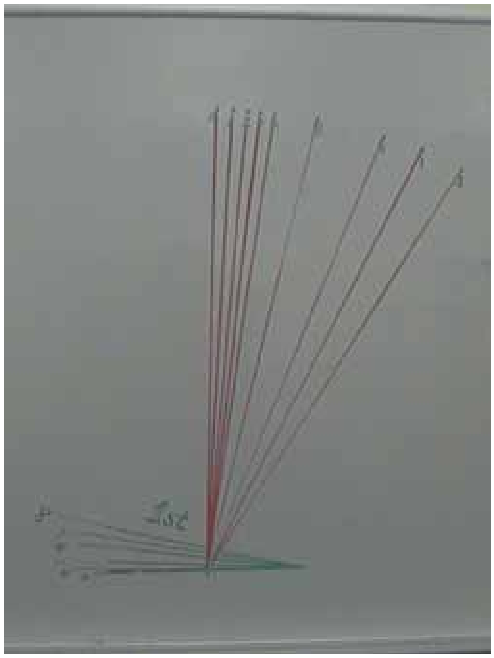
(3) The rotational displacement of the cone body and the bending point of the rubber base caused by the external force were marked on a white board (Figure 3-16, c and d).

(4) The weight of the counterpoise was increased and steps (2) and (3) were repeated.

(a)

(b)

(c)



(d)

Figure 3-16 (a) The experimental setup of the cone body slope test (b) The pulling force is kept horizontal (c) The displacement is marked on the whiteboard for both cone and base (d) The final positions with different applied forces

3.10.3 Experimental data

Table 3-8 The relationship between external force and the displacement of the cone

Counterpoise Mass(kg)	Applied Force(N)	Cone angle(degree)	V_{cone}(mm)	H_{cone}(mm)
0	0	0	872.0	0
0.5	4.905	1.96	870.3	29.8
1.0	9.810	3.87	867.4	58.7
1.5	14.715	5.42	864.9	82.1
1.7	16.677	7.24	862.7	109.7
1.9	18.639	12.59	850.4	190.4
2.1	20.601	20.97	817.6	314.8
2.2	21.582	25.89	793.6	387.5
2.3	22.563	31.19	755.4	460.5
Note: V_{cone} means the vertical height of the cone, and H_{cone} is the horizontal displacement of the cone.				

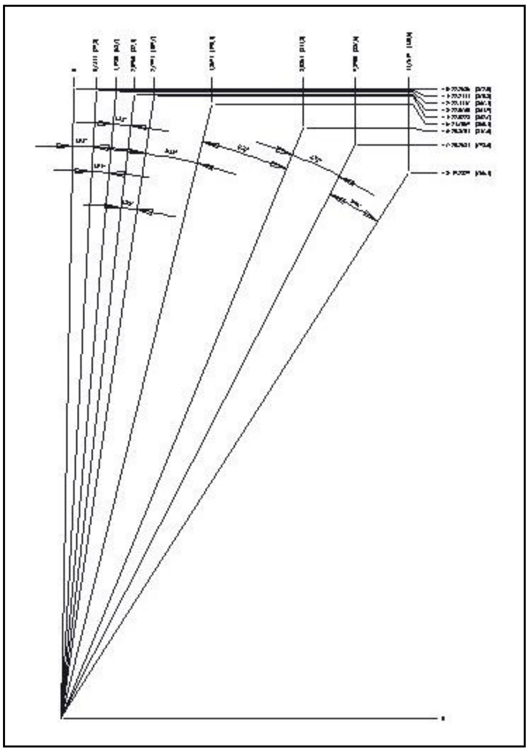


Figure 3-17 Visual representation of the data in Table 3-8

Table 3-9 The relationship between external force and the displacement of base

Counterpoise Mass(kg)	Applied Force(N)	Base Angle(degree)	V_{base}(mm)	H_{base}(mm)
0	0	0	0	370.0
0.5	4.905	0	0	370.0
1.0	9.810	0	0	370.0
1.5	14.715	0	0	370.0
1.7	16.677	0.98	6.3	369.5
1.9	18.639	3.61	23.0	364.9
2.1	20.601	8.30	52.0	357.0
2.2	21.582	11.90	69.8	352.7
2.3	22.563	14.08	86.2	343.7
Note: V_{cone} means the vertical height of the cone, and H_{cone} is the horizontal displacement of the cone.				

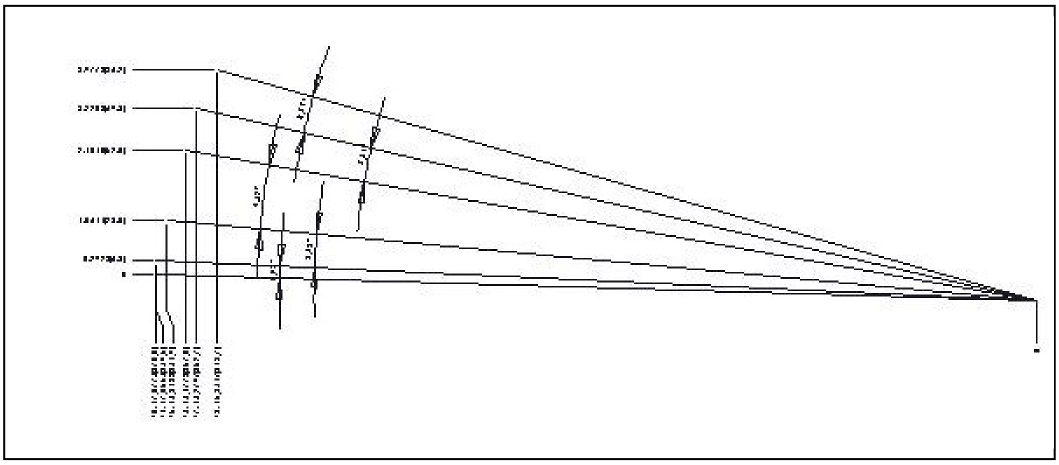


Figure 3-18 Visual representation of the data in 3-9

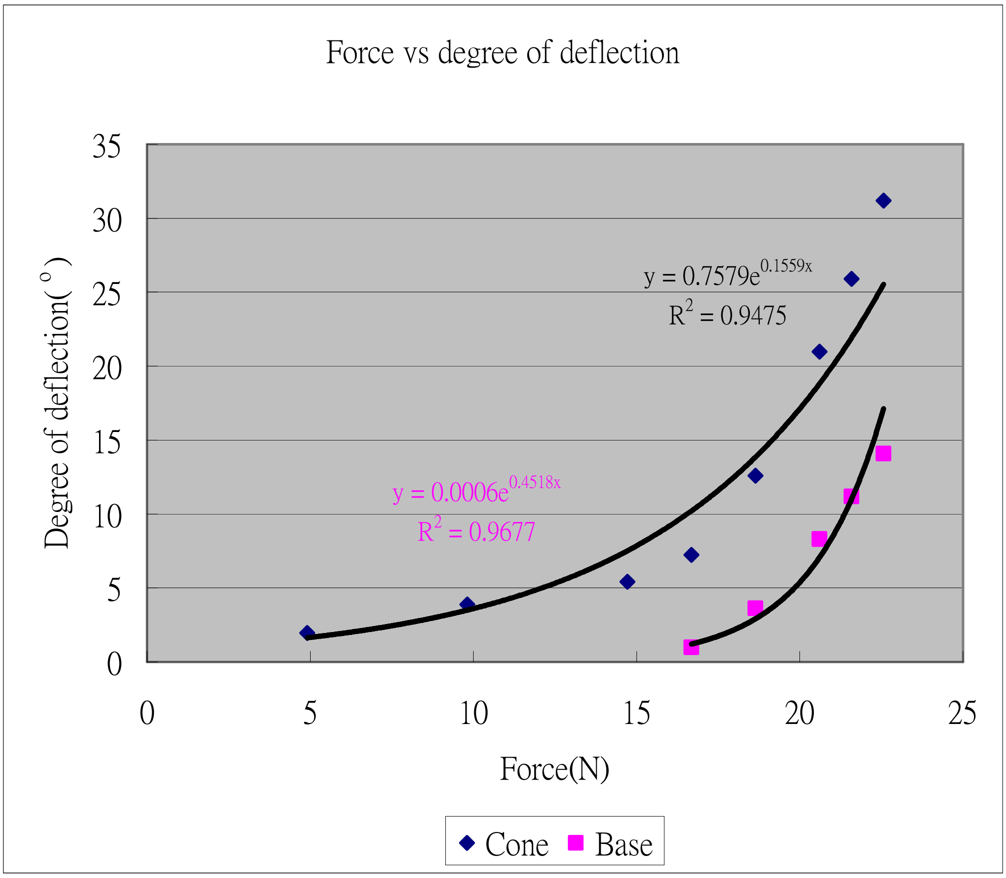


Figure 3-19 A graph of the external force vs. degree of deflection

Chapter 4

Simulation

4. Simulation

4.1 Introduction

Computer simulation has become an important tool for product design and manufacture. The speedy development of the personal computer which promotes a capability of speedy computational calculations facilitates the accuracy of computing simulation quite substantially. No matter how the computer participates in product design or manufacture, the cost and time of manufacturing are reduced. Therefore, in this project, the computational simulation plays an important role in optimizing the road cone design.

Initially several 3D solid models using Solidworks were produced and models were then transferred into finite element analysis (FEA) models that are going to be used for analysis using COSMOSWorks. These models include the rubber strip, rubber base and the whole traffic cone. The experimental data deriving from the experimental work were used as data for the FEA models. The simulation results were then compared with the experimental data. For validation purposes if the difference between simulation and experimental data is within 15%, the validation model was accepted, otherwise the relevant parameter or setting was changed for further analysis. The validation process is shown in Figure 4-1.

The following sections (4.2 to 4.6) describe the simulations used in this analysis. The results from these simulations are given in chapter 5.

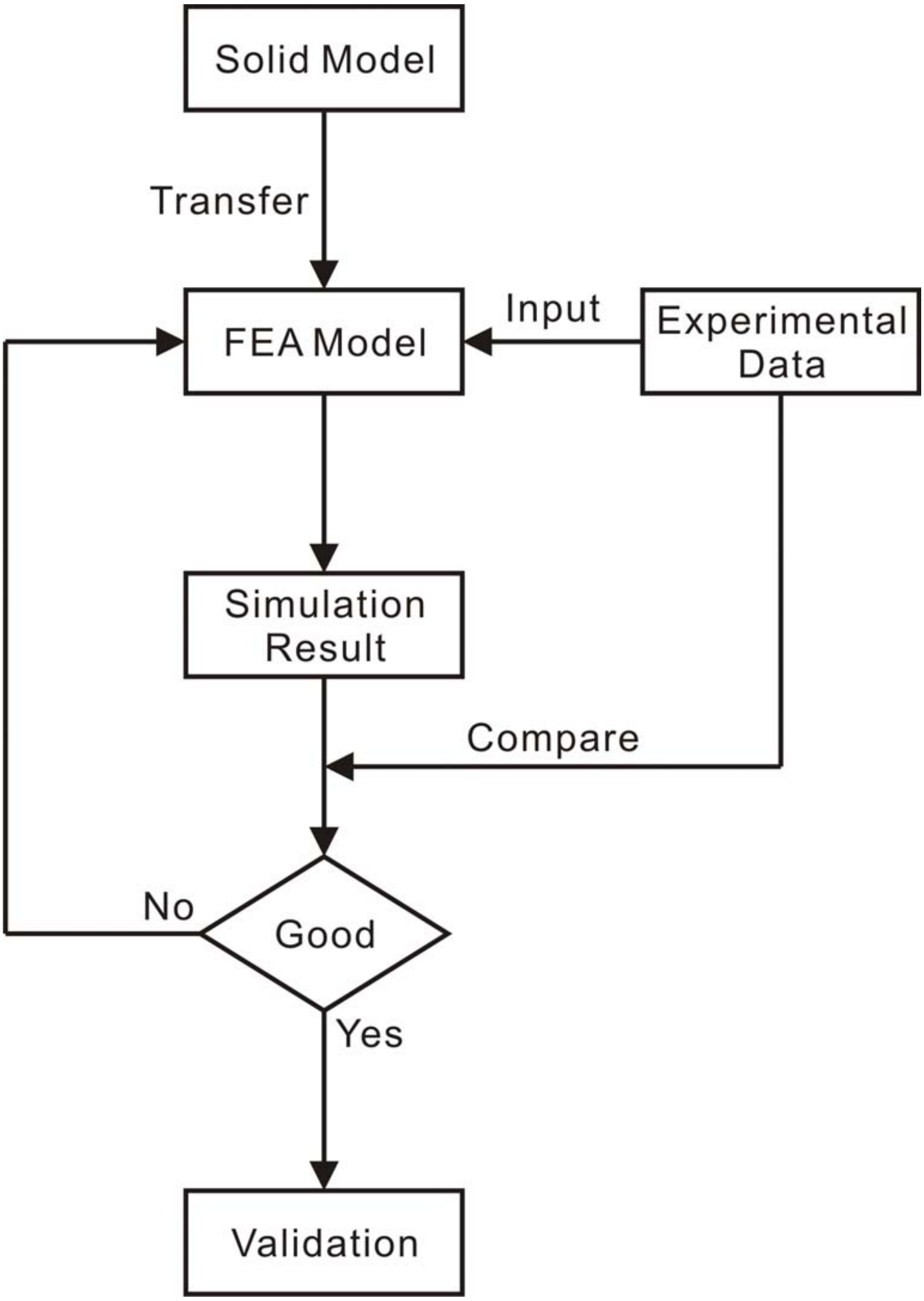
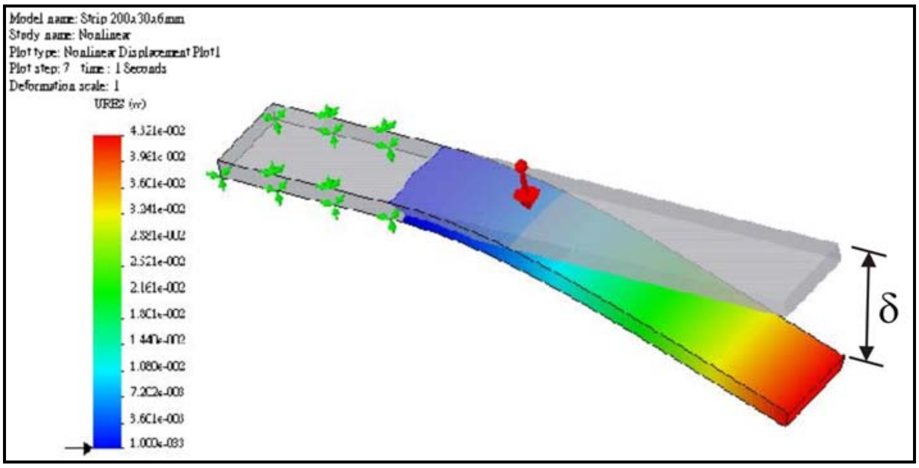


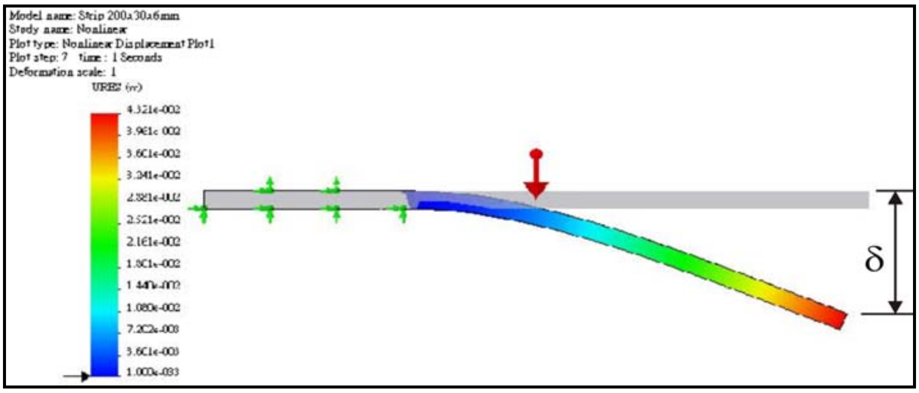
Figure 4-1 Validation flow

4.2 Simulating a drooping rubber strip

A 3D model of a rubber strip was set up in SolidWorks and this was then used for FEA simulation using COSMOSWorks. The data obtained from the experiments described in section 3.3 and 3.8 was used in the FEA simulation. The rubber strip was modeled as a cantilever with a length and thickness fixed at 200mm and 6mm respectively but with three different widths of 30mm, 40mm and 50mm respectively. They are shown as Figure 4-2.



(a)



(b)

Figure 4-2 The simulation view of (a) isometric (b) front

COSMOSWorks allows for the analysis of linear elastic and non-linear elastic materials. The materials used in the traffic cone design are the flexible materials, polyethylene and rubber. To compare the accuracy of these two methods, both linear and non-linear simulations were tried. It was found that the results for nonlinear analysis were closer to the real experimental data, and therefore nonlinear analysis became the main simulation method in this project. Table 4-1 compares the results for the static and nonlinear analysis using COSMOSWorks with experimental data in a drooping test of a rubber strip.

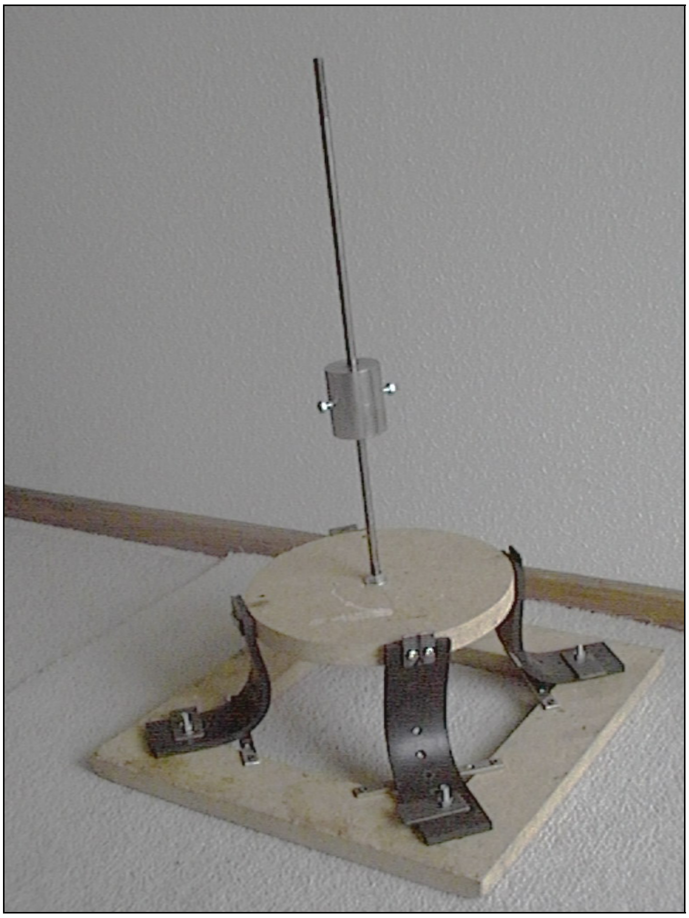
Table 4-1 Results for the experimental work and simulation

Unsupported Length (L/m)	Displacement under self weight (d/mm)								
	W30(54g)			W40(71g)			W50(89g)		
	Exp.	Non.	Static	Exp.	Non.	Static	Exp.	Non.	Static
0.08	7.0	4.8	4.8	4.0	4.7	4.7	6.0	4.7	4.6
0.10	15.0	11.8	11.9	11.0	11.6	11.7	12.0	11.4	11.5
0.12	29.0	23.9	24.5	21.0	23.7	24.4	22.0	23.2	23.8
0.14	38.0	42.9	45.6	37.0	42.4	45.1	37.0	41.5	44.2
0.16	68.0	69.0	78.1	63.0	68.0	76.9	62.0	67.1	76.0

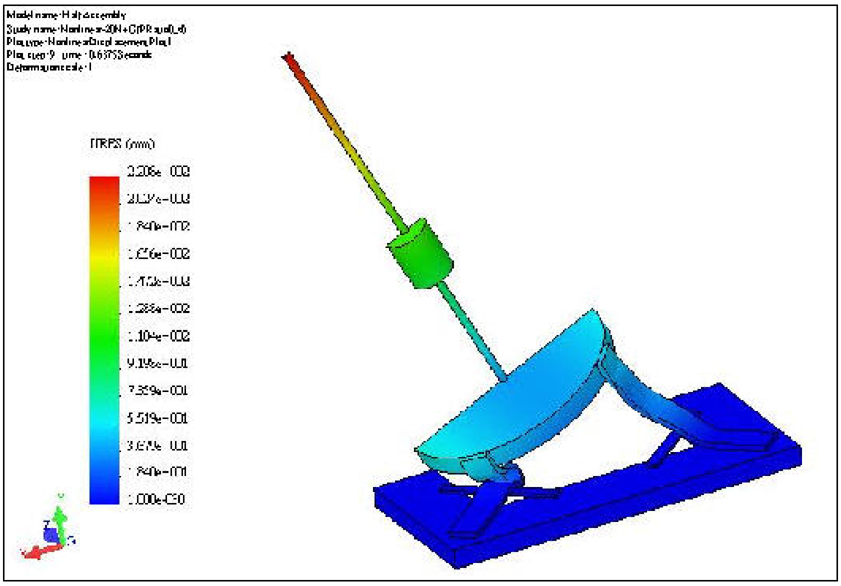
4.3 Simulation using a simplified test-rig model

In order to simulate more accurately the deflection in the rubber strips between the cone and base (section 4.2) when subjected to external forces, an arrangement for testing was designed and set up as shown in Figure 4-3 (a). The test rig is made from compressed wood and steel. The wood and steel when compared with the rubber can be regarded as absolutely rigid objects for modeling purposes, thus removing uncertainties, caused by elastic deformation in the cone, from the modeling.

The bending behaviour and change in deflection of the rubber strips could be easily observed and recorded through this simulation. Simultaneously, the differences between experimental data and simulation could be readily compared, and then the key role and characteristics of the rubber strip could be understood in further designs.



(a)



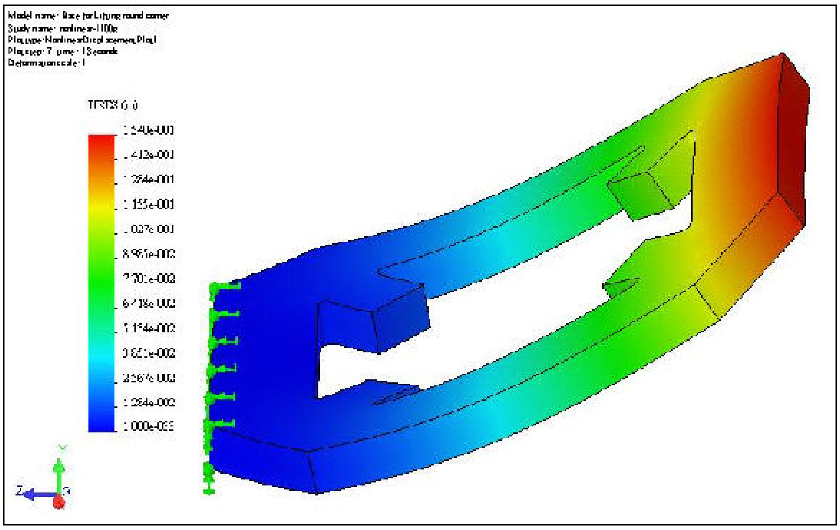
(b)

Figure 4-3 (a) Test rig for the rubber strips (b) An example of the deformation in the rubber strips given by an FEA model

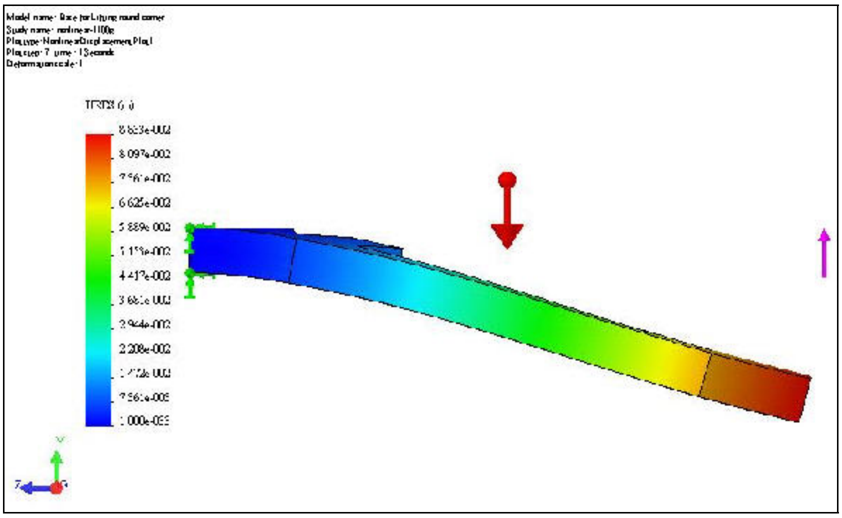
4.4 The deflection of the rubber base

In addition to a computer simulation of the rubber strips, a computer simulation and analysis of the rubber base is another important step. The rubber base was first tested as described in section 3.9 using the arrangement shown in Figure 4-4, and the results were compared with the computer simulation. The computer simulation did not agree with the experimental results. The reasons for this difference were analyzed and found to be caused by a lack of experimental data, in that some important experimental parameters had not been recorded. Although the base deflection and lifting force during the experiment had been measured, the contact area between the base and the desktop, and the resultant reaction force, could not be determined. The lack of these data directly affected the accuracy of the simulation. The simulations of the rubber base are shown as Figure 4-5. The lifting force is 10.791 N (1.1 kg) for both cases.

Figure 4-4 The lifting test of rubber base



(a)



(b)

Figure 4-5 The result of simulation obtained (a) without gravity (b) with gravity.

4.5 Simulation of the traffic cone prototype

When the entire prototype of the traffic cone was meshed for analysis using COSMOSWorks, a failure message from the application appeared. The main reason for this was the large number of mesh elements and consequently too many post processing calculations which were beyond the programme's capacity to solve.

To reduce the number of meshing nodes, advantage was taken of the model symmetry. In this way, the modeling simulation was carried out using one half of the system and replacing the other half by appropriate boundary conditions. Not only is the number of mesh elements reduced, but the accuracy and performance of the analysis is improved.

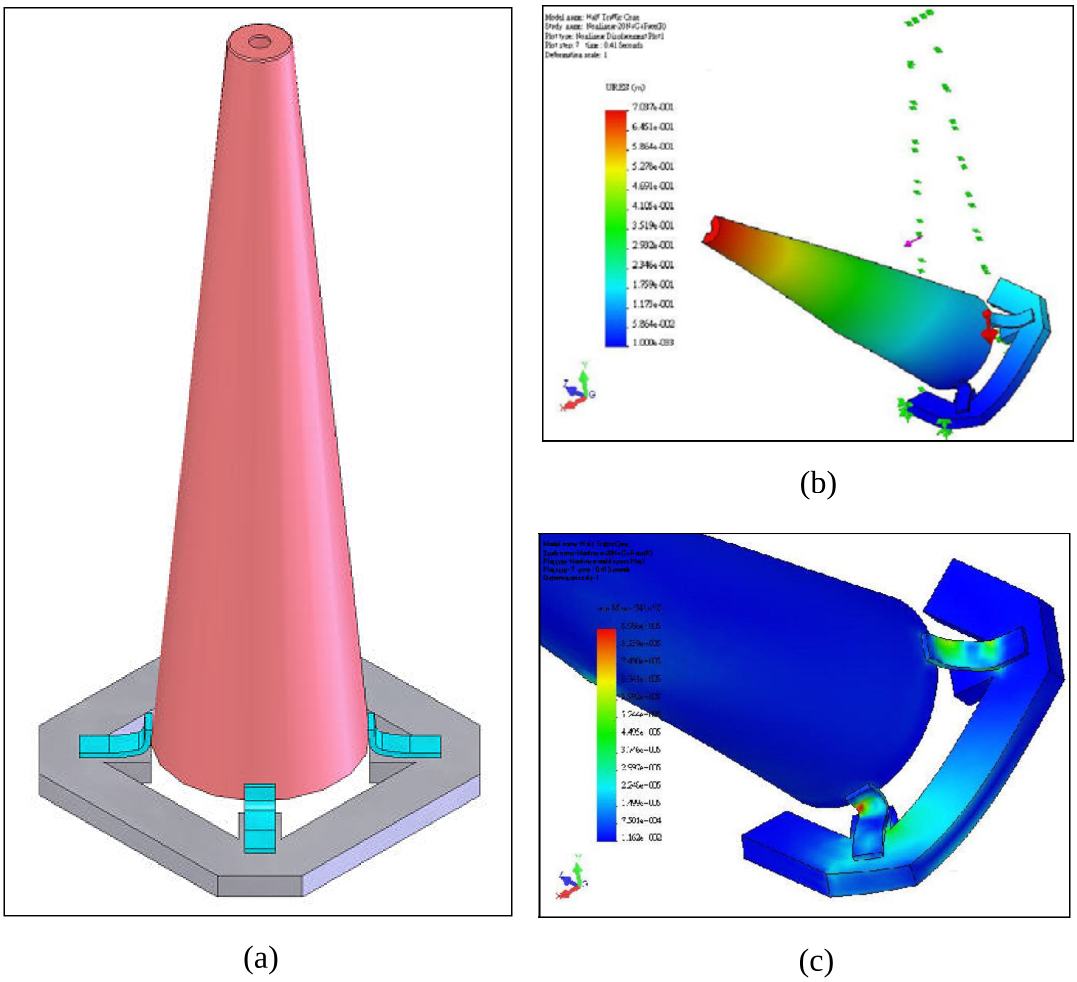


Figure 4-6 (a) The complete traffic cone model (b) The deformation analysis for a half model (c) The stress distribution in the cone

4.6 Dynamic simulation

Because the analysis using COSMOSWorks is a nonlinear static analysis, its capability to simulate the effect of impact loading is insufficient for a prediction of real behavior. A more specialized dynamical analysis is therefore required in order to simulate the toppling behavior of the cone.

Three different models were created for this dynamic simulation, using the same materials properties and part dimensions for each model. But there is only one difference between these three models. The first model used shorter rubber strips to link the cone and base, and the second model longer rubber strips. The third model was orientated so that the impacting force was in a direction along the base corner diagonal. Displacement images were captured continuously and shown in Figure 4-7 to Figure 4-9. All these models simulated the traffic cone when knocked by a cement ball (described in chapter 3, section 3.4). The images show different time periods up to two seconds. From a comparison of these three dynamic models we can observe the result of simulation (the blue traced line); in the first of the dynamic models (Figure 4-7), the cone continued to move a short distance after the traffic cone toppled over. In the second dynamic model, the cone remained stationary after toppling over. And in the third model the cone didn’t topple over. Obviously, the strength of absorption of the impacted energy for the three cases can be ordered as:

Third (diagonal position)>Second (longer strips)>First (shorter strips)

The simulation results corresponded to the experimental behavior.

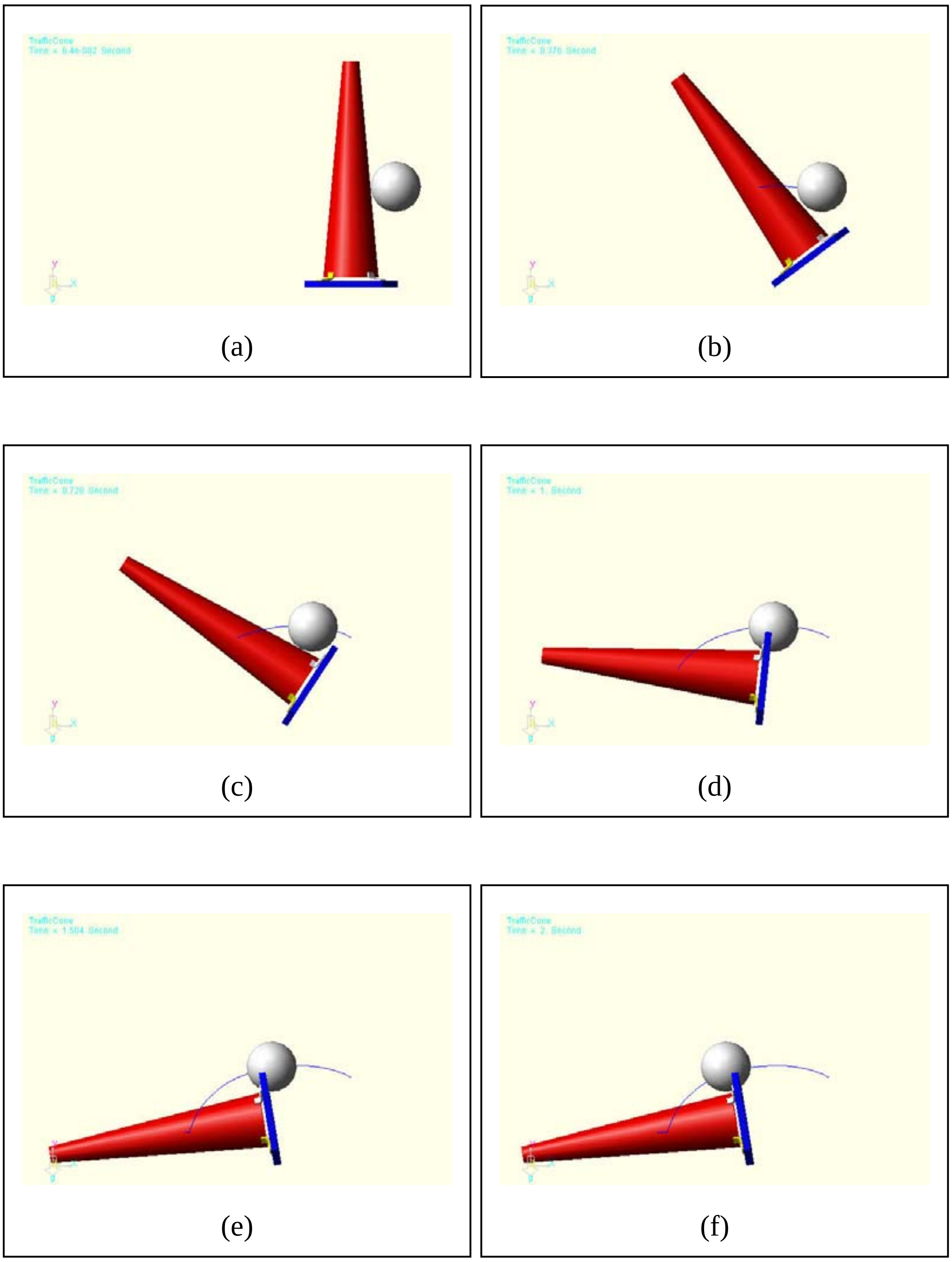


Figure 4-7 A dynamic simulation of the traffic cone with the shorter strip when knocked by cement ball

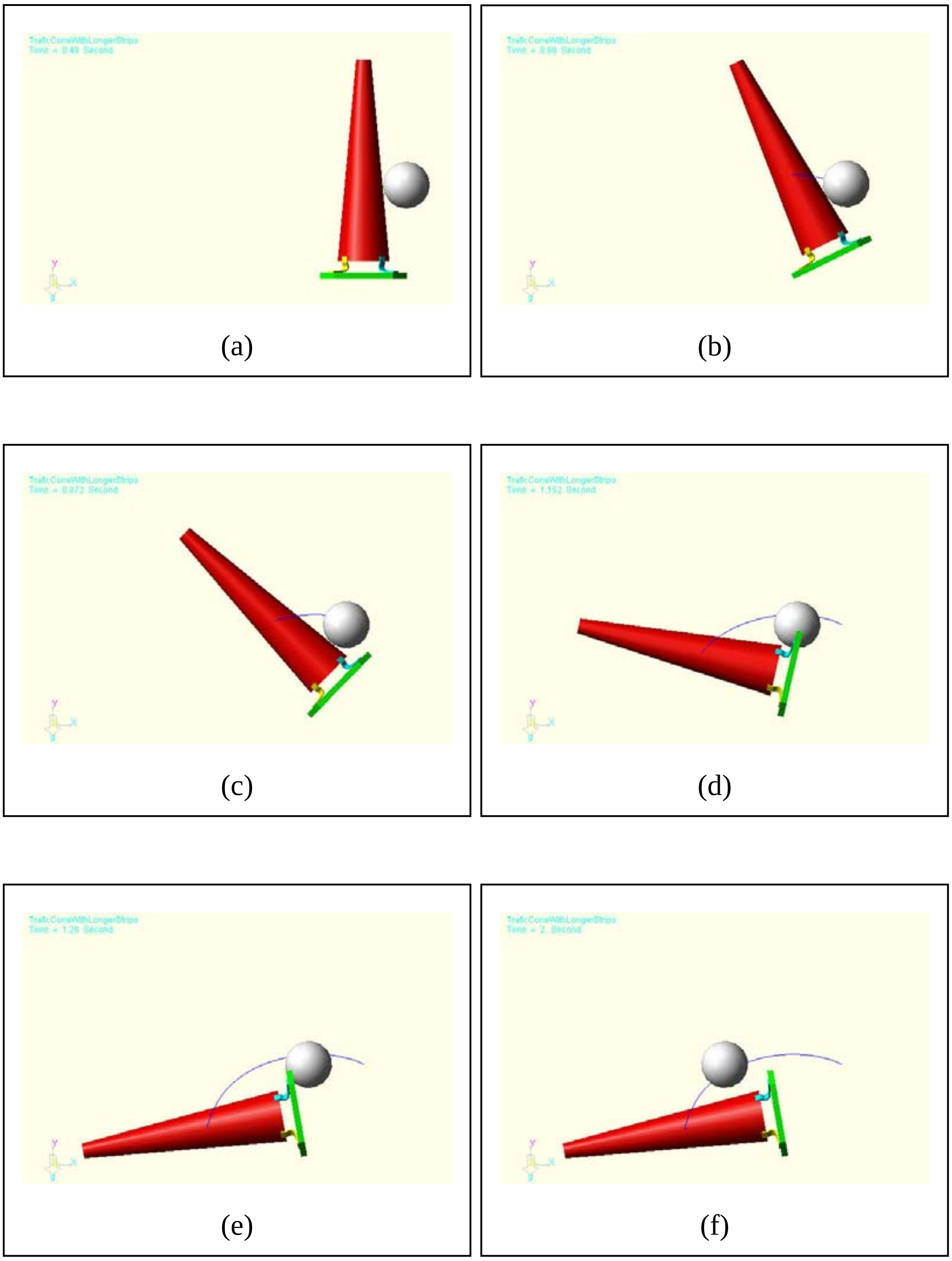


Figure 4-8 A dynamic simulation of the traffic cone with the longer strip when knocked by cement ball

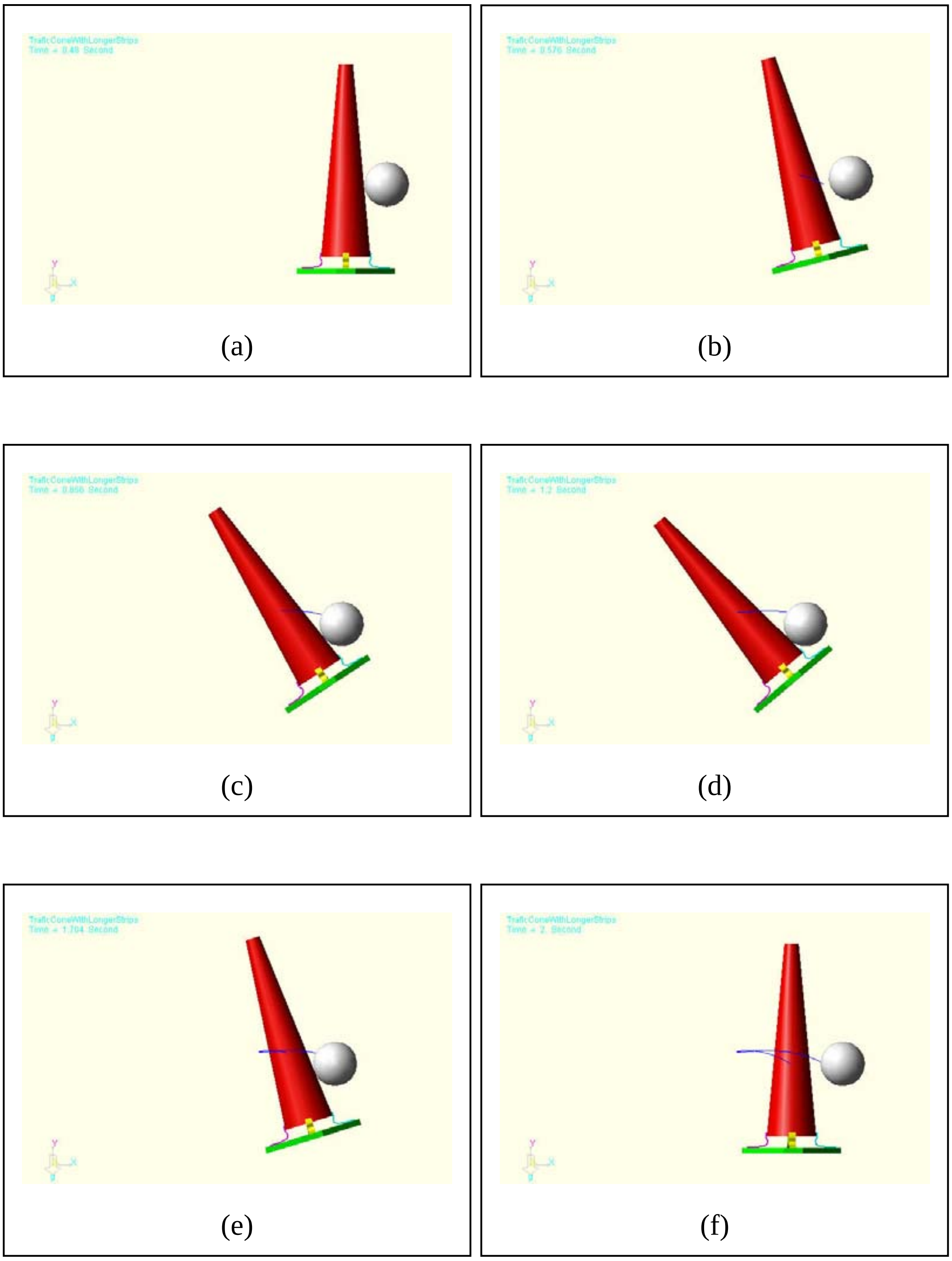


Figure 4-9 A dynamic simulation of the traffic cone with impact force directed along the base diagonal

Chapter 5

Results and Discussion

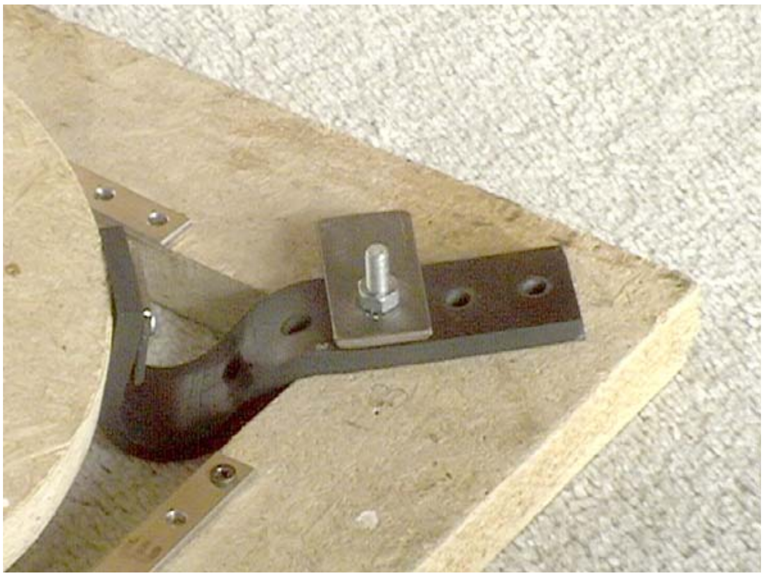
5. Results and discussion

From the experiments and computer simulation of the original prototype, a number of factors have been identified as influencing the stability of the traffic cone. These are: the weight of the complete traffic cone, the centre of gravity of the traffic cone, the softness and flexibility of the cone, the length, width and thickness of the rubber strip, the shape and thickness of the rubber base and the method by which the various components are linked to one another. In order to simplify the analysis, the upper cone was regarded as rigid, rather than flexible, and the key points of analysis were focused on the length of the rubber strip and the thickness of the rubber base.

5.1 The effect of the rubber strip length

The experimental work to investigate the effect of different rubber strip lengths (section 3.5), indicated that while a longer strip can absorb more impact energy than a shorter one, it also causes a reduction in stiffness. An excessively long rubber strip cannot support the weight of the upper cone, and cannot right the conical part from a toppled position (Figure 5-1). When a short piece of metal was placed below the rubber strip, the supporting force of the rubber strip showed a significant increase (Figure 5-2).

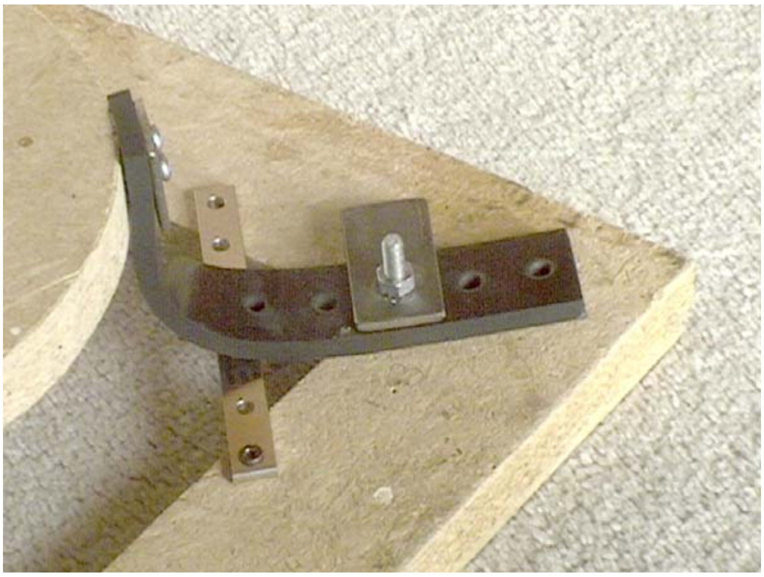
(a)



(b)

Figure 5-1 An overly long rubber strip cannot support the upper cone weight

(a)



(b)

Figure 5-2 A piece of metal placed below the rubber strip improves the supporting force of the rubber strip

Results for the bending stiffness of the rubber strip were given in section 3.8 of chapter 3, and the relationship between the unsupported length of the rubber strip and the stiffness of the strip is shown in tables 5-1 and 5-2 for different strip widths. It was found that the maximum supporting length of the rubber strip is about 0.09m (the third hole) for a rubber strip of 30mm width and about 0.11m (the fourth hole) for a rubber strip of 40mm width. Figure 5-3 shows the effect that an excessive supporting length of rubber strip has upon the cone's operation. The weight of the cone is about 1.69kg (16.6 newton).

Table 5-1 The 30mm width of rubber strip.

Unsupported length	Sum of the distributed force	Mid. Deflection	Stiffness
(L/m)	(F/N)	(d/m)	(k/Nm^{-1})
0.08	0.213	0.00145	147.05
0.10	0.266	0.00353	75.29
0.12	0.319	0.00732	43.57
0.14	0.372	0.01357	27.44
0.16	0.425	0.02315	18.38

Table 5-2 The 40mm width of rubber strip.

Unsupported length	Sum of the distributed force	Mid. Deflection	Stiffness
(L/m)	(F/N)	(d/m)	(k/Nm^{-1})
0.08	0.284	0.00132	214.96
0.10	0.355	0.00322	110.06
0.12	0.425	0.00668	63.69
0.14	0.496	0.01238	40.11
0.16	0.567	0.02111	26.87

(a)

(b)

Figure 5-3 The cone will not right itself when the length of the rubber strips is excessive

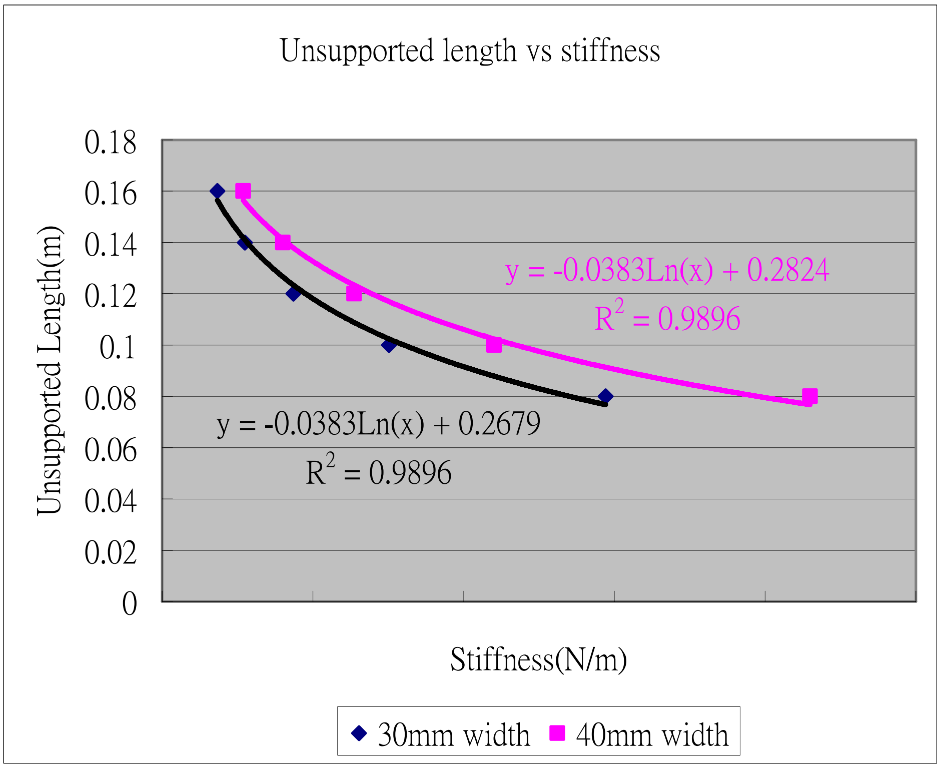


Figure 5-4 The stiffness of different width's of rubber strip

Figure 5-4 Shows that the wider of the two rubber strips has the greater stiffness. The equation for calculating stiffness can be obtained from the curves in Figure 5-4 as follows:

$$S_{30mm} = e^{(L-0.2679)/-0.0383} \text{ --------------------------------- (1), and}$$

$$S_{40mm} = e^{(L-0.2824)/-0.0383} \text{ --------------------------------- (2)}$$

Where S is the stiffness and L is the unsupported length of the rubber strip. With the 30mm model, the cone righting ability is only maintained up to a maximum unsupported length of 0.09m. The other model with a 40mm strip width has a greater restoring ability, so that the cone is able to right itself with the rubber strip up to the fourth hole, which is at a length of is 0.11m. When the cone is pushed to one side by an external force, at least two rubber strips will push the cone back, so that it rights itself. The experimental results in tables 5-1 and 5-2 lead to a cone performance equation:

$L \times S \geq W/2$ -- (3)

where W is the weight of the cone in newtons. If the product of L and S is greater than half the weight of the cone (the total cone weight is 1.6kg which is about 16.6 N), the rubber strip can push the cone back successfully. If not, the cone will not right itself. For example, the 30mm model's unsupported length is 0.09m using equation-1 it can be calculated that the stiffness is about 108N/m, so $0.09 \times 108 = 9.82 \geq 16.6/2$. Therefore the strips can push the cone back. But when the unsupported length is 0.11m, the stiffness is about 64N/m. $0.11 \times 64 = 7.04 < 16.6/2$ therefore the restoring force is insufficient to right the cone.

On the other hand, using equation-2 the 40mm rubber strip stiffness is estimated to be 90N/m when the unsupported length is 0.11m. Applying the performance equation: $0.11 \times 90 = 9.9 \geq 8.3$. When the unsupported length is 0.13m, the stiffness will be 53N/m, and so $0.13 \times 53 = 6.89 < 8.3$. Therefore to right the cone a longer rubber strip can be used when the width of strip is increased.

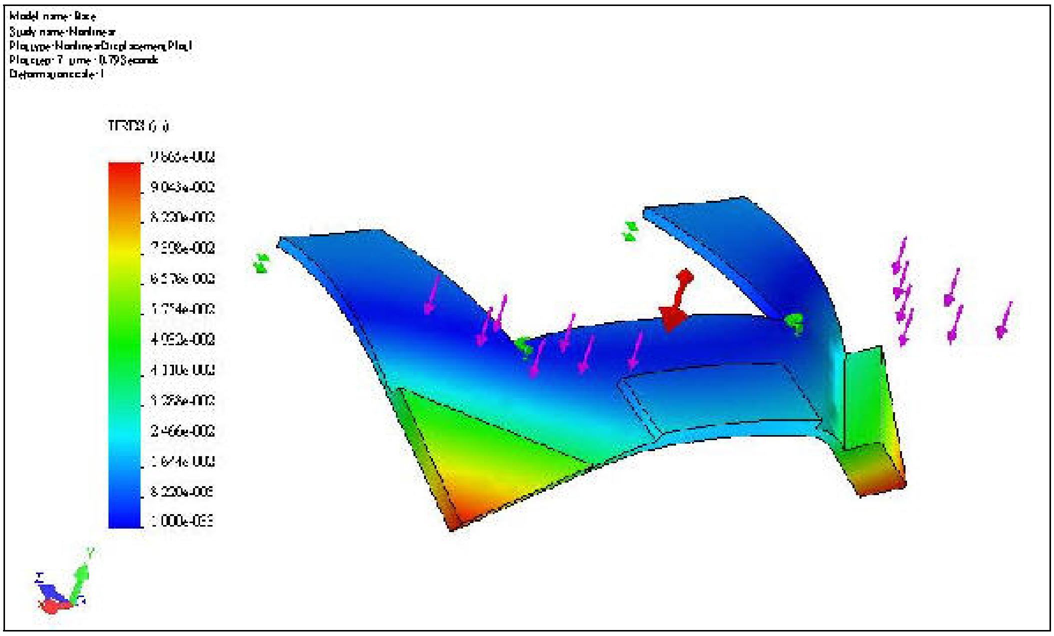
5.2 The thickness of the rubber base

Another key factor in this project is how the rubber base should be designed in terms of shape and thickness. Certainly, the weight of the rubber base may be increased by adding to the thickness of the base, therefore moving the mass centre of the whole traffic cone lower to increase its stability. However, if the thickness of the rubber base is increased too much, the bending stiffness of the rubber will become higher. This leads to a reduction in the absorption of the impact energy, and the advantageous properties of rubber in rebounding and flexibility may be lost.

On the other hand, a rubber base which is too thin will cause insufficient restoring force to right the cone after an impact. Figure 5-5a shows the flexibility of a 6mm thick base and Figure 5-5b shows the deformation analysis with gravity on the fixed inside corner.

Four pre-made triangular iron blocks were placed on the four corners of the rubber base in order to increase the bases stability, with each block weighing about 0.5kg. Experimental observation, showed that when the weighted uniform base of 6mm thickness was bent by an applied force, the resultant shape of the base was similar to a letter S, as shown as Figure 5-6b. Such deformation was unable to produce a large enough restoring force, so that the cone would right itself only slowly or not at all. This shortcoming could however be overcome by utilizing the difference in the thickness of the rubber base, and this difference also changed the bending position (see Figure 5-6d).

(a)



(b)

Figure 5-5 The base deformation when (a) holding the cone (b) in the computer simulation

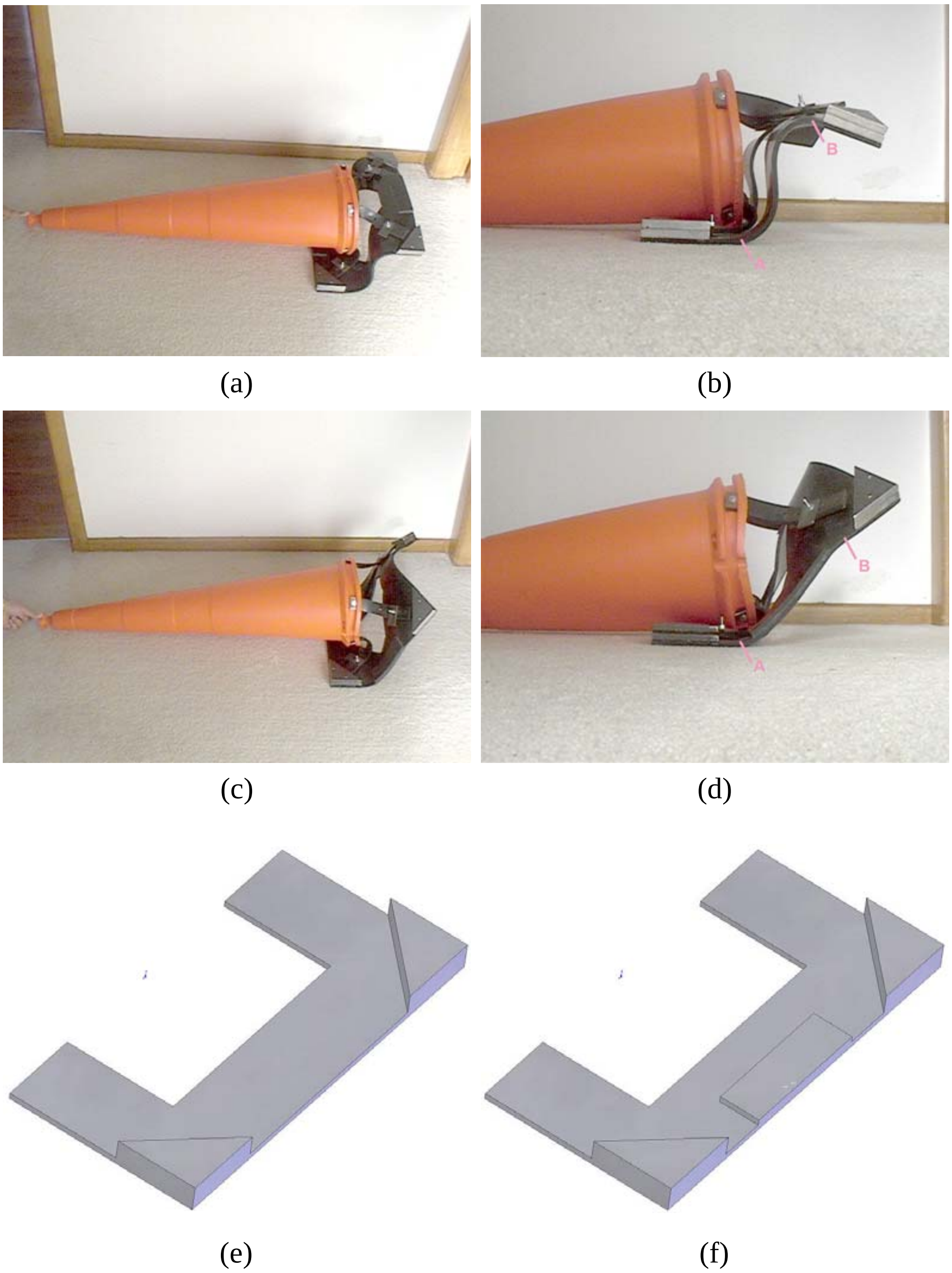
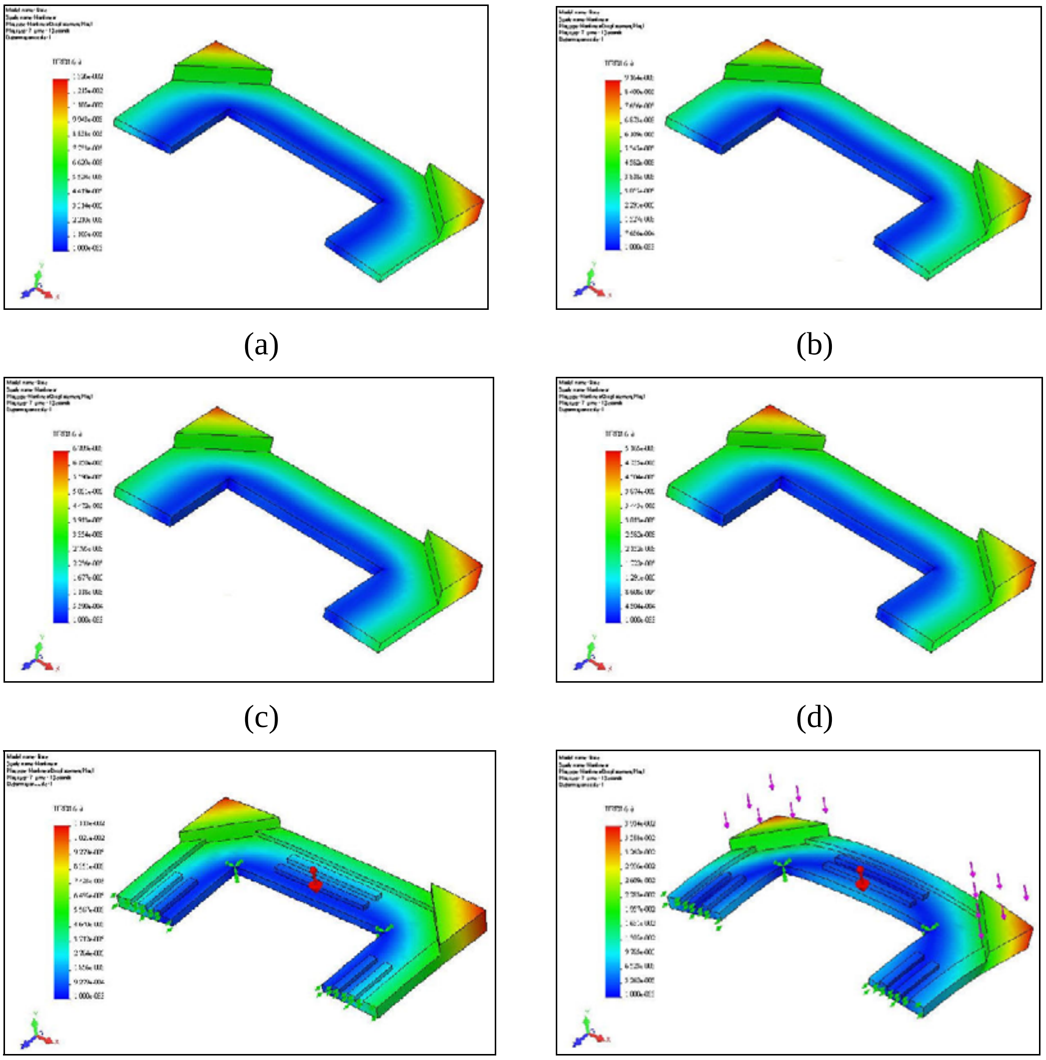


Figure 5-6 (a) and (b) are different views of the same deformation , (c) and (d) are different views of the same deformation , (e) and (f) are two different thickness models

In order to restrict the deformation of the base, the rubber cannot deform too much, so the thickness of the rubber base needs to be increased. After a series of experiments and simulations, the data showed that a better rubber base thickness would be between 10mm to 16mm, as shown in Figure 5-7a to d. Therefore, 10mm was decided as a final base thickness for this project. In addition, as mentioned above, the bending points of the rubber base needed to be changed. Four rubber blocks were placed on every side of the rubber base to stop it from deforming in the manner shown in Figure 5-7e and f.



(a) (b)

(c) (d)

(e) **(f)**

Figure 5-7 Base thickness of: (a) 10mm (b) 12mm (c) 14mm (d) 16mm, (e) and (f) both 10mm (e) had no force on the corners but (f) does

Chapter 6

Conclusions and Recommendations

6. Conclusions and Recommendations

6.1 Conclusions

- The structure of the traffic cone was designed so that the integrated pieces were made into two single parts. To keep the original appearance, the traffic cone was divided into the upper cone and the lower base; these single parts were put together in the simplest way, so that the assembly time could be reduced.

- The selected materials were Polyethylene (PE) for the upper base and ethylene propylene diene monomer (EPDM) rubber for the lower base. Both of these materials are recyclable. For common commercial grades of medium-density and high-density polyethylene, their prices are lower than other general materials. Polyethylene usually can be dissolved at elevated temperatures in aromatic hydrocarbons (i.e. toluene, xylene) or chlorinated solvents (i.e. trichloroethane, trichlorobenzene). Ethylene Propylene Diene Monomer (EPDM) is a synthetic rubber - a highly flexible stable material. EPDM's balance of physical properties and chemical resistance makes it ideal for the rubber base.

- Of the selected materials, PE costs about 2 dollars (NZD) per kilogram, and every kilogram of EDPM cost about 2.5 dollars (NZD). As the upper cone weighs around 850 grams, and the lower base weighs about 2.5 kilograms, the total cost of materials is about 8 dollars (NZD)

- To increase service stability, the upper cone needs to be designed to become thicker gradually from top to bottom (not changing the total weight). This will make the centre of gravity decrease.

- The required length of the rubber strip can be calculated according to the equation L*S>W/2. If the thickness of the supporting rubber strip is 6mm and the width is 30mm then the length can be set as 70mm, incorporating a factor of safety (F.S.) of about 1.5.

- The stability of traffic cone could be increased by adding weight onto the rubber base. The bending behavior of the rubber base can be changed by using areas of varying rubber thickness to increase the rubber base's restoring ability.

6.2 Recommendations

- Consider embedding cheaper materials other than the original EPDM rubber into the four corners of the rubber base, to decrease the total cost and to increase the stability of the traffic cone.

- Consider embedding other materials into the rubber base, like spring steel to increase the base's restoring force ability.

- Analyze different shapes for the rubber base, for example change the original square base into a circular base in order to determine the optimum base shape.

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Appendix A

The Transit Regulations

B2 DELINEATION DEVICES

B2.1 General

Delineation devices such as cones, tubular delineators and barrels, must be specifically designed and manufactured for temporary traffic management use.

B2.2 Colour

All delineation devices, e.g. cones, tubular delineators and barrels, must be fluorescent orange with:

- CIE chromaticity co-ordinates in accordance with Table 2.1 of the joint Australian and New Zealand Standard AS/NZS 1906.4:1997;
- Minimum luminance factors in accordance with Table 2.2 of the joint Australian and New Zealand Standard AS/NZS 1906.4:1997.

In addition, the internal colour of the bases of cones, tubular delineators and barrels must be either white or fluorescent orange, to ensure the device remains visible if knocked over.

B2.3 Dimensions

On ***all Levels*** of roads the cones, tubular delineators and barrels used for delineation purposes must have a minimum height of 900mm and an unballasted weight not exceeding 7kg.

Notes:
1. 450 mm high cones may only be used to delineate and protect wet road markings.
2. Double stacking of cones is not acceptable as such practice will exceed the maximum permitted weight and is prohibited, with effect from 31 July 2005.
3. In locations where high wind speed is a concern heavier weight cones, up to 7kg, of a ‘slimline’ profile should be used.

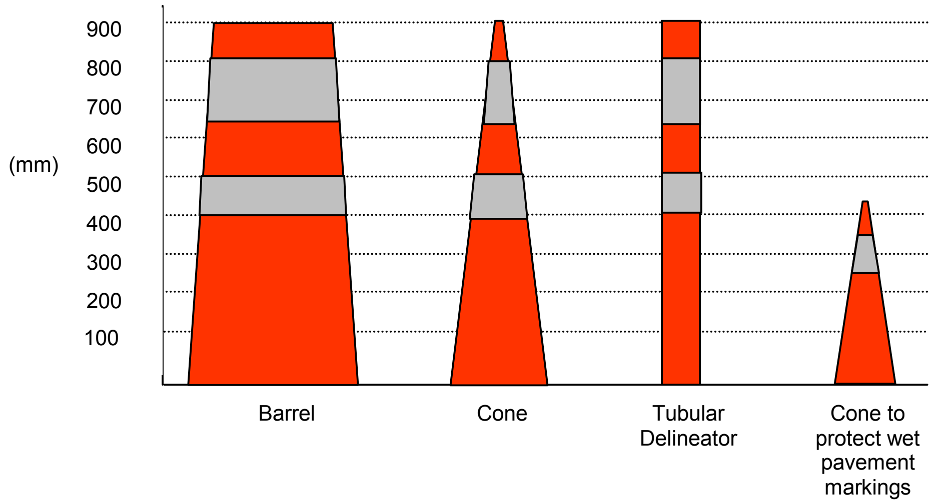
All cones must:

- be sufficiently stable to remain upright in service,
- have a base designed to stop the cone from rolling if knocked over, and
- be capable of returning to their original shape after impact.

All barrels must have:

- a minimum base dimension of 600mm x 600mm,
- rectangular or slightly chamfered corners, and
- a stable base design that will accommodate either sandbags or water as ballast.

EXPLANATORY NOTE - Retro-Reflective Band Set Out (Refer Section B2.4)



Barrels used for temporary traffic management must not:

- be made of steel,
- be weighted with any material that could be a hazard if struck,
- have ballast placed on top of the barrel, and
- be filled with water where below freezing conditions are expected.

All tubular delineators must:

- be at least 100mm wide.

B2.4 Retro-Reflectivity

Delineation devices must have white retro reflective bands that:

- meet the requirements for Class 1 material in Table 2.1 of the joint Australian and New Zealand Standard AS/NZS 1906.1:1993, and
- conform to the number, width and height requirements of Table B2.1.

Size (mm)	Use	No. Bands	Band Width (mm)	Height of bottom edge of band from ground (mm)
900	All roads	2	100	400 (1st band)
			150	650 (2nd band)
450	To protect freshly painted road markings	1	100	250

Table B2.1: Retro Reflective Bands for Delineation Devices

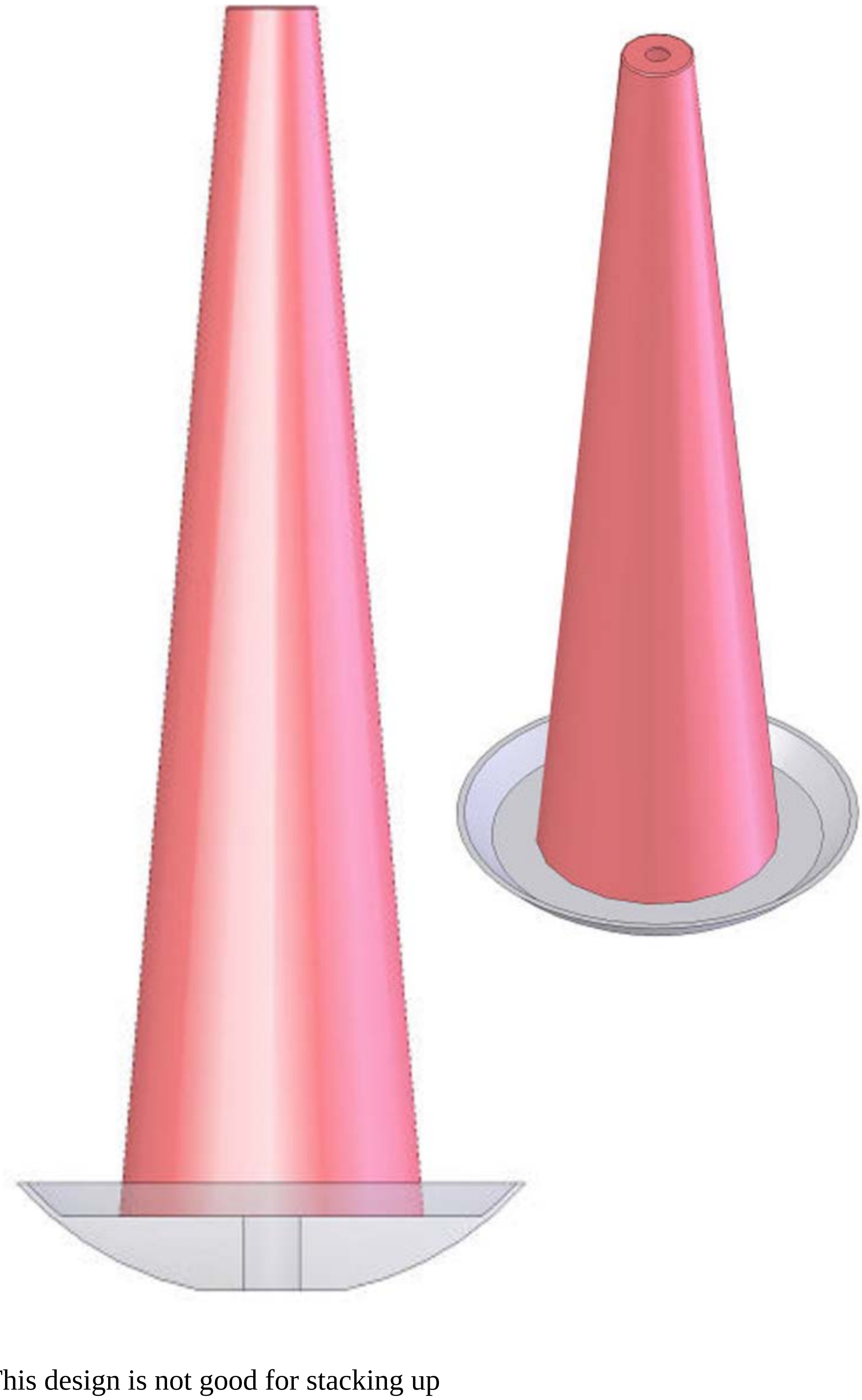
B2.5 Application Date

All delineation devices must comply with the above requirements.

Appendix B

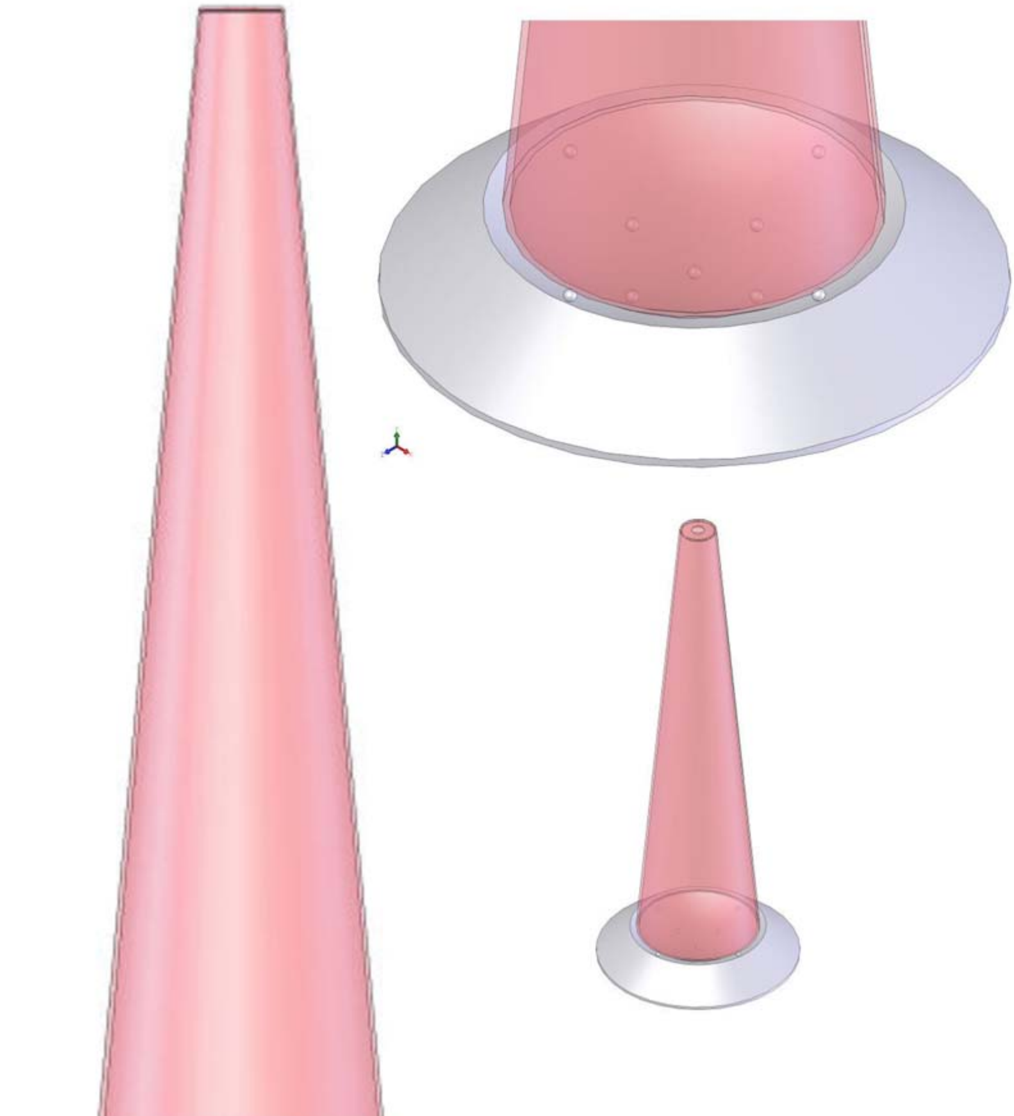
Concept Generations

Concept 1



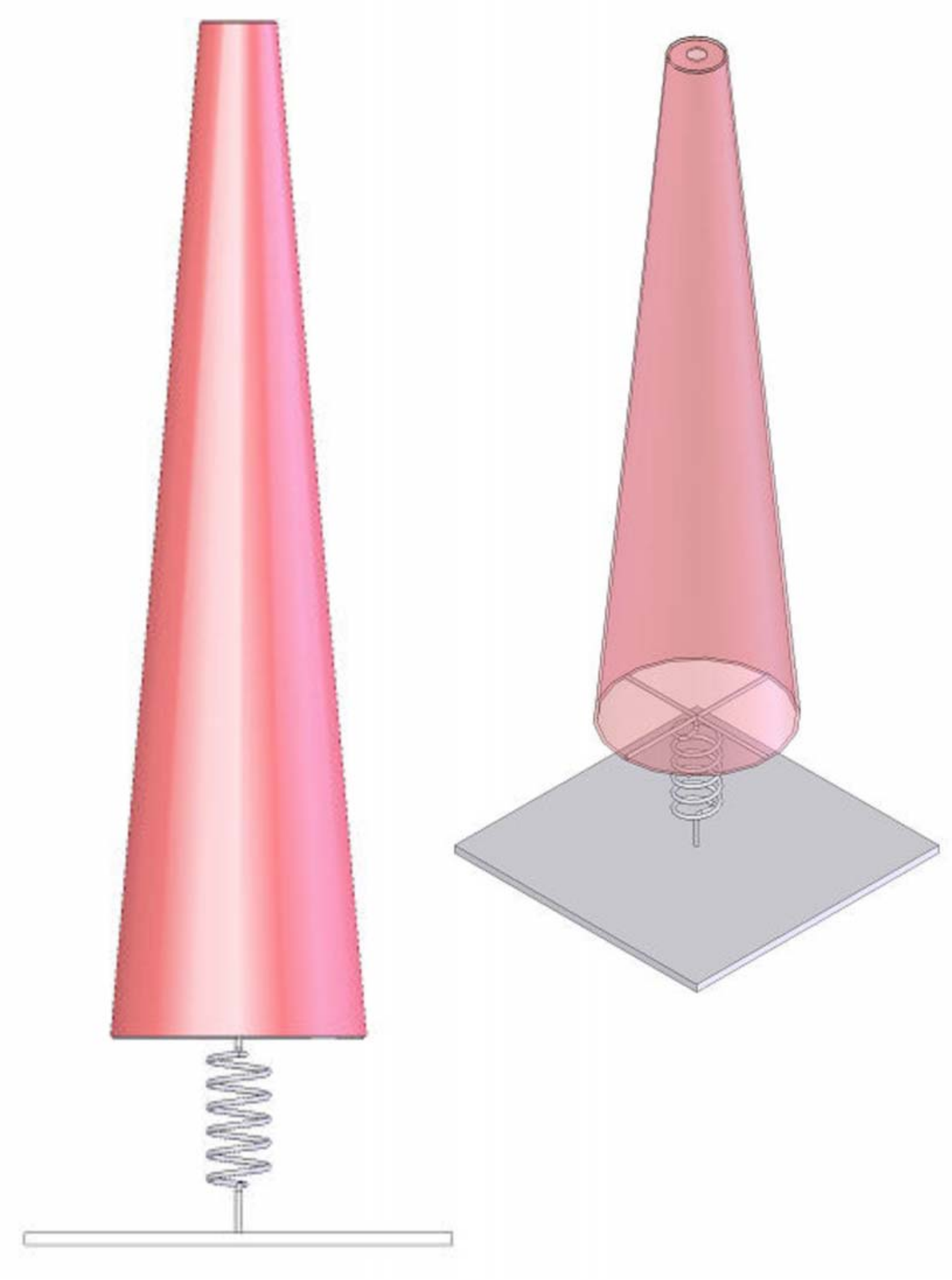
This design is not good for stacking up

Concept 2



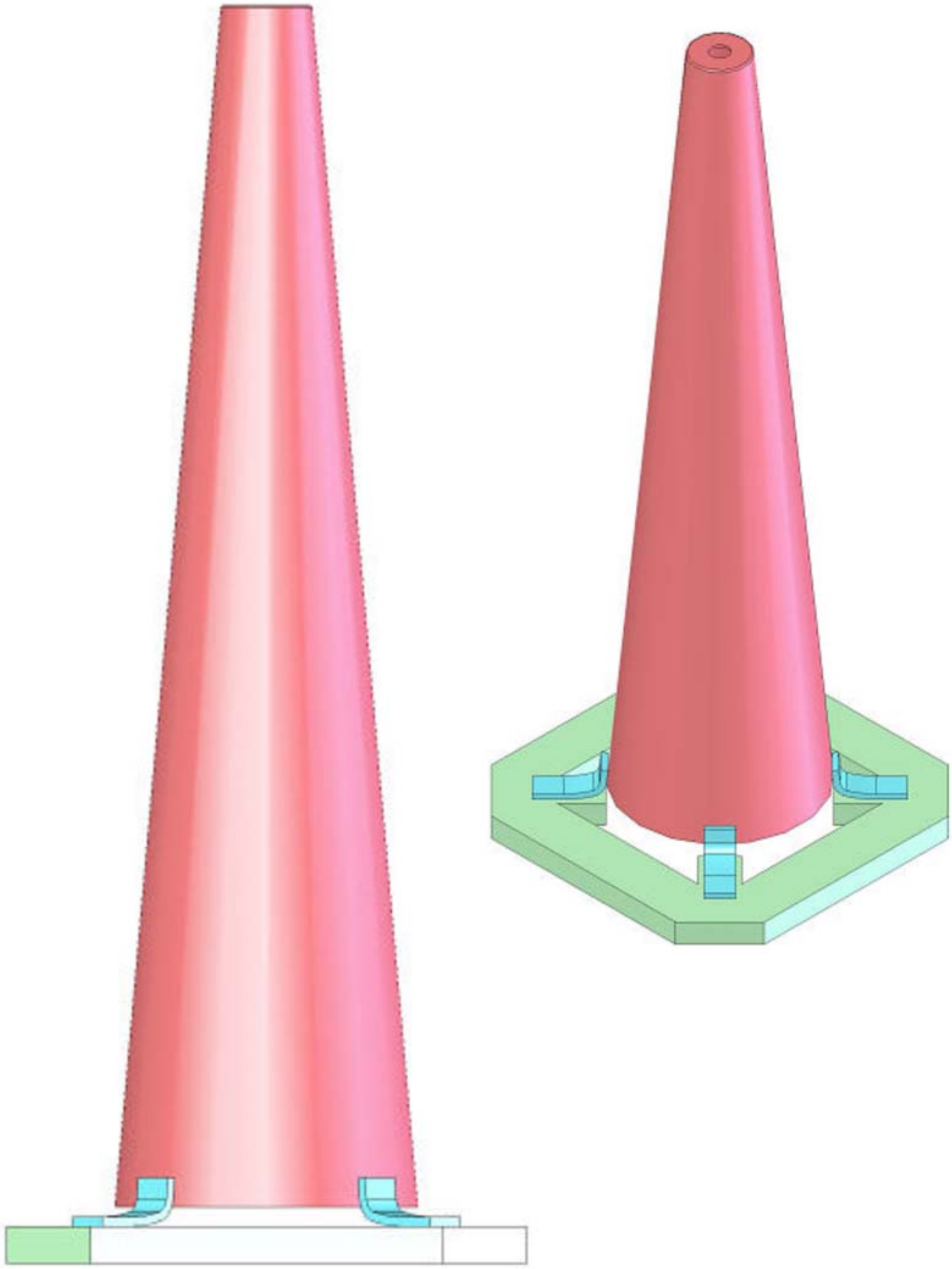
This design is not good for stacking up

Concept 3



This design is not good for stacking up

Concept 4



This design is good for stacking up