ABSTRACT

FINITE ELEMENT ANALYSIS OF SKIN INJURIES BY WATER JET CUTTING

by

Syed Muhammad Arif

High pressure water jets are used in industry for cleaning and cutting purposes. These devices can generate pressure upto 400 MPa. As high pressure water jets become more widespread in industry, injuries will be seen with great frequency. Penetrating injuries by these devices can produce minimal external evidence of extensive soft tissue injury. To know the extent of injury, it is important to study the relationship between operating parameters of water jet and the skin layers. A computational analysis is carried out using finite element method to find the effects of water jet pressure on the skin layer. Finite element skin model is made and the analysis is carried out at different pressure. Linear and non linear static analyses are done here to study the behavior of skin layers under pressure. The results obtained from both analyses shows linear effect that is elastic behavior. The skin materials rupture before going into the plastic region. The results show that the layer of skin will start to shear at about 45 MPa of water jet pressure. The epidermis bears most of the stresses and is deformed, other layers are also deformed but do not reveal high stress concentration. High stress concentration are seen in the dermis where there are not enough collagen fibers.

FINITE ELEMENT ANALYSIS OF SKIN INJURIES BY WATER JET CUTTING

by
Syed Muhammad Arif

A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Manufacturing Systems Engineering

Department of Industrial and Manufacturing Engineering

May 1997

APPROVAL PAGE

FINITE ELEMENT ANALYSIS OF SKIN INJURIES BY WATER JET CUTTING

Syed Muhammad Arif

Dr. George Hanna Abdou, Thesis Advisor — Date
Associate Professor of Industrial and Manufacturing Engineering, NJIT.

Dr. Tina Taiming Chu, Committee Member — Date
Assistant Professor of Mechanical Engineering, NJIT.

Dr. Carl Wolf, Committee Member — Date
Professor of Industrial and Manufacturing Engineering, NJIT.

BIOGRAPHICAL SKETCH

Author : Syed Muhammad Arif

Degree : Master of Science

Date : May 1997

Undergraduate and Graduate Education

- Master of Science in Manufacturing Systems Engineering,
  New Jersey Institute of Technology, Newark, NJ, 1997

- Bachelor of Science in Mechanical Engineering,
  N.E.D University of Engineering and Technology, Karachi, Pakistan, 1995

Major : Manufacturing Systems Engineering

ACKNOWLEDGMENT

The author wishes to thank his thesis advisor, Prof. George Abdou, for patiently reviewing the progress of the thesis at every stage and helping him to plan it efficiently. This thesis would not have been successful but for his invaluable guidance, continuous motivation and sincere concern.

Further, I would like to express my gratitude to Dr. Carl Wolf, and Dr. Tina Chu for serving as committee members and providing necessary guidance for this work.

Thanks also to the librarians at NJIT for their help in survey of research papers relevant to the thesis topic.

Lastly, thanks to all my friends for their support and cooperation.

To my beloved Parents

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

Chapter **Page**

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Water jet machining is a process used primarily to cut and slit porous nonmetals such as wood, paper, leather, and foam. Two water jet machining process variations are also available for performing wire stripping and deburring.

Water jet machining removes material through the erosion effects of a high velocity, small-diameter jet of water. The principle behind this method of cutting was first observed in the early 1900s by workers in steam plants. When a pinhole leak developed in a high pressure steam line, workers discovered that the resulting steam jet had sufficient power to quickly and cleanly cut through objects such as wooden broomstick. Although this demonstrated the potential usefulness of high-velocity jets as a cutting tool, no significant effort was made to apply this technology until the 1960s when Norman Franz patented the technique for producing a coherent, high-velocity stream of water. This invention, which became the basis for today's water jet machining technology, was refined during the 1960s and was first introduced to industry as a new cutting tool in the early 1970s.

Water jet machining provides omnidirectional cutting capabilities at very high speeds with a resulting edge quality that is usually superior to other conventional cutting processes. Unlike conventional mechanical cutting processes, down time for the replacement of worn or broken cutting tools is virtually non existent with water jet machining because the tool never dulls or breaks. Additionally, the health hazards associated with cutting materials such as asbestos and fiberglass are minimized because almost no airborne dust is generated by this process.

The exact equations governing the interaction of a high velocity water jet and the workpiece material are complex and detailed. A thorough discussion of these specifics can be found in Hashish and Reichman (1980).

In general, the water jet machining process is performed with a collimated jet of water that exits a specially shaped nozzle at velocities of 900 m/sec i.e. over 2000 mph. Approximately 25 mm from the nozzle, a shroud of mist begins forming around the water jet core. The shroud of mist rapidly diverges because of interactions with air, but the tight water jet core continues to provide the cutting action. This cutting action can be maintained through soft solids that are up to 250-mm thick.

1.1 Water Jet Cutting Capabilities

A wide range of materials can be cut with water jet machining, but because erosion is the method of removal, materials must be porous, fibrous, granular, or soft.

The water jet machining cutting rates can be extremely high. In fact, when cutting most materials, rates are so fast that current computer numerical control machines are outpaced by the process. When this happens, thickness may be built up by multilayer cutting, thus slowing the cutting rate, or the cutting nozzle may be built up by multilayer cutting, thus slowing the cutting rate, or the cutting nozzle may moved by a cam driven actuator. Predrilling of starting holes is not necessary when shape cutting with water jet machining. The jet can pierce material in any location and then proceed to cut in any direction of the material. This omnidirectional cutting ability allows complex shapes with almost any radius to be easily fabricated. Kerfwidth is approximately 0.025 mm larger than the nozzle diameter, thus enabling the saving of material by closely nesting shapes.

Certain materials that are too thick to be cut in a single pass can be cut with multiple passes without degrading the cut quality. If the first pass can produce a well defined slot in the material, then a second pass can be used to cut deeper. Multipass cutting uses less energy per unit length than a single pass with a more powerful jet (Hashish and Du Plessis, 1978). Of course, there is a maximum thickness that can be achieved with multipass cutting, and this, ultimately, depends upon the particular material being cut.

The surface finish of cut edges is good, with no burrs and no heat damage. However surface finish and edge straightness degrade as material becomes very thick or when cutting speeds are too fast. Tolerances are also a function of material type and thickness, but they are usually within ±0.1-0.2 mm.

The process summary of water jet cutting is listed in the Table 1-1.

Table 1-1 Water Jet process summary.

ADVANTAGES	**DISADVANTAGES**
No tool resharpening costs.	Equipment is moderately expensive
Minimum kerfwidth.	Not well-suited for hard, nonporous materials.
Easily automated.	Brittle materials may crack.
Omnidirectional cutting.	Contaminated water must be treated before disposal.
Dust-free process.	Noise and **high pressures require safety considerations**.
High cutting rates.	
Absence of heat-affected zone	.

1.2 Problem Definition

The devices used for water jet can generate up to 55,000 psi, delivering 60 gallon/minute at velocities of 900 mph. At high pressure these devices can be used to cut concrete and steels. Penetrating injuries by these devices can produce minimal external evidence of extensive internal damage. Knowledge of the specific characteristics of these injuries is important for the appropriate evaluation and treatment of these patients. The greater pressures and nozzle velocities can result in very extensive soft tissue injury. High pressure water jet injuries should be considered surgical emergencies. A high index of suspicion of associated internal injuries and aggressive surgical intervention are required.

Use of water jet is rapidly increasing in surgery. They are used in dissection and are used to recanalize arterial occlusive lesions.

Since the use of water jet is increasing day by day therefore the probability of injuries caused by water jet is also increasing. Injuries caused by water jet and the use of water jet as a surgical tool needs a lot of attention.

It is necessary to study the complexity of injuries caused by water jet in order to provide necessary medical treatments. To know the extent of injury, it is important to study the relationship between the operating parameters of water jet and the structure as well as mechanical properties of the skin.

Greater pressure and nozzle velocities can result in very extensive soft tissue injury. The pattern of tissue damage can be similar to that of high velocity missile or shot gun wounds. The small entrance wound and lack of exit wound is not indicative of the extensive disruption of deeper tissues that can result from the dispersion of kinetic energy after penetration of the skin by the water jet.

The majority of high pressure injection injuries can produce serious damage to the skin. Nevertheless, the injury may follow a relatively benign courses if the injected substance possesses a less harmful nature. Treatment for these injuries requires immediate and aggressive surgery in most circumstances, but conservative treatment may be justified in certain instances.

CHAPTER 2

LITERATURE REVIEW

Different papers were searched and reviewed regarding the injuries caused by water jet process and its application on surgical side. Not many work in this area was found but some of the papers which were found are as follows.

2.1 Injuries Caused by Water Jet Process

Some of the papers found about the injuries caused by Water jet process are summarized below.

Moshe Kon (1985) presented a paper on high pressure water jet injury of the hand. A rare case of high pressure injection injury to the thumb with water is reported. A 32 year old man sustained a high pressure injection injury to his left thumb with a water gun that is used to clean Carburetors. Physical examinations revealed that the thumb was slightly swollen and tender. The point of entry was a small lesion on the palmar side of the distal phalanax. X-ray films of the thumb showed no abnormalities. The mechanism of damage is thought to occur from a sudden increase in pressure in a relatively small closed space resulting in ischemia and is chemical iteration from the injected material that causes an inflammatory response with accompanying edema and infection from foreign material. Conservative treatment of a patient with this type of injury makes admission and close follow-up mandatory, immediate surgical intervention must be considered in cases of deterioration of the clinical course.

A case report on Penetrating Intra-abdominal injury caused by high pressure water jet from British Medical journal (1969) is reported. A man was cleaning a heat exchanger tube bundle. As the lance was withdrawn, the water jet was accidentally directed towards his abdomen. The only abnormalities were minimal tenderness and guarding in the right iliac fossa, and a semicircle of 5 cm radius comprised of tiny pin-point puncture wounds of the skin low in the fossa, the appearance closely resembling a superficial abrasion. The wound appeared to have been at a tangent to the abdominal wall. The patient was treated and the recovery was uneventful.

Richard L. Harvey (1996) presented a paper on major vascular injury from high pressure water jet. A 33 year old man cleaning industrial storage tanks with high pressure water jet device sustained lacerations to the left medial thigh and calf. There was minimal bleeding at the scene. Emergency examination revealed much more soft tissue damage than suspected from the small external wounds. The small entrance wound and lack of exit wound is not indicative of the extensive disruption of deeper tissues that can result from dispersion of kinetic energy after the penetration of the skin by the Water jet. In this case, the lacerations appeared superficial, and digital exploration failed to reveal the extensive underlying muscle and vascular damage.

Chung-Ho Pai (1991) presented a paper on high pressure injection injuries of the hand. During a 4 year period, eight cases of high pressure injection injury were encountered. The types of injected material were paint, grease, water, benzene, and hydraulic oil. Time is an important factor regarding the results, while the types of injected material modify the clinical courses. It is advisable that the etiology of high pressure injection injury should be established initially, and this factor be taken into consideration in choosing treatment options. Radiographic examination revealed varying distributions of radio-opaque density in those injured from paint and grease injections, while air density from water injection was demonstrated. Leucocytosis was found in all patients except the two with water and benzene injection injuries. An unusual case was from water injection injury. Conservative treatment only, including compression dressing and hand elevation in conjunction with aforementioned adjuvant therapy, led to full recovery of the hand.

William A. walker (1989) presented a paper on high pressure water injury. A 21 year old man was operating a high pressure water jet device at 8,000 p.s.i. and 25 g.p.m. The nozzle accidentally passed over the medial aspect of his right thigh, resulting in a large laceration with profuse hemorrhage. The physical findings were 18-cm laceration medially, 4 cm laceration laterally, soft tissue air and the extent of injury was superficial femoral artery and vein laceration, loss muscle mass, contused femoral and sciatic nerve. The treatments were artery and vein reconstruction, mult. re-explorations with debridement and irrigation, antibiotic therapy. The results showed wound infections.

A case report on high pressure water jet injury is reported fro British Medical Journal (1980). A patient, 32 year old experienced diver, was lowered to 150 feet under the sea to clean by high pressure jet on of the “sea legs” of an oil rig. The jet gun had been left at a site by previous diver. The water was murky and he could not see the gun. He picked up the hose and began to withdraw it when the gun fired for a moment causing him to drop the hose. He felt that he had received a blow on the abdomen but did not realize quite what had happened. He groped for the gun and used it for a minute or two. The pain in his abdomen became more severe and he asked to be taken up. He was decompressed routinely with a pause of three minutes at 50 feet. The time from the start of the descent to the return to the surface was 14 minutes. The jet had drilled a neat hole through both suits and entered the abdominal wall. He was transferred to a hospital. There was a small puncture wound about 0.25 cm in diameter on the interior abdominal wall. A chest radiograph was normal and x-ray examination of his abdomen showed no evidence of free intraperitoneal gas and no abnormal soft tissue shadows. Because of the mechanism of the injury laporatomy was done through a right paramedian incision excising the entrance wound. The wound enlarged as it went deeper. The patient had an uneventful convalescence and went home after eight days. The patient's heavy protective clothing decreased the velocity of the jet and dispersed the reduced kinetic energy in the abdominal wall, so that it caused no internal injuries. Since the jet was fired only momentarily the mass of water was minimal.

Landau D., and Berson D. (1995) presented a paper on high pressure water jets as a cause of severe bilateral intraocular injuries. The purpose of which is to draw attention to the characteristics features of eye injuries caused by high pressure water jets. Three patients are examined with bilateral eye injuries caused by directed high pressure water jets. All three patients had reduced visual acuity bilaterally, extensive eyelid ecochymosis, subconjunctival hemorrhages, hyphema, iris sphincter rupture, transient increase in intraocular pressure, and inferior commotio retinae. These injuries were confined primarily to the lower parts of the eyes. High pressure water jets may cause bilateral eye injuries affecting primarily the anterior and inferior parts of the eyes. Because of concern about late effects of injuries, long-term follow-up is recommended.

2.2 Water Jet as a Surgical Tool

Different papers were reviewed about the use of water jet as a surgical tool, the summary of some papers are listed below.

A. Cuschieri (1994) presented a paper on experimental evaluation of water jet dissection in endoscopic surgery. The problems associated with high velocity high pressure water jet dissection were investigated by in-vivo experiments using endoscopic equipment. Three problems were identified: backspray with fouling of the optic, poor control of the depth of cut, and detachment of tissue fragments and isolated cells which contaminate the operative field. The first two problems were resolved by adoption of hooded handpiece and the incorporation of an adjustable back stop. A "dry" system which enables the evacuation of the back spray may deal with the problem of contamination of the operative field by detached cells but further in-vivo experiments are needed to confirm this. Until then, water jet cutting is considered unsafe for both open and endoscopic surgery in patients undergoing extirpative procedures for cancer because of the risk of tumour seeding within the peritoneal cavity.

Masami kobayashi (1995) presented a paper on water jet angioplasty - an experimental study. The usefulness and safety of water jet angioplasty was studied in vitro, using agar phantom and autopsied aorta, and in vivo in acute and chronic arterial occlusions in mongrel dogs. At an injection rate of 1 ml/s, the water jet produced erosion of the agar surface when the distance between the catheter and the agar was 1mm. With an injection rate of 1.5 ml/s, erosion was produced at a distance of 15 mm from the catheter tip. When the water jet was directed at an arterial wall, intimal ablation and ruptured elastic fibers were found histopathologically. A smaller angle between the vascular wall and the catheter was associated with less vascular damage. In vivo, water jet angioplasty was effective against acute abstructions, but not against chronic abstructions. These results suggest that water jet angioplasty may be effective against arterial obstruction due to acute thrombus.

Rau, H. G. (1995) presented a paper on laparoscopic liver resection with the water jet dissector. Laparoscopic liver resection requires careful patient selection. Tumor size and location have a major influence on the feasibility of a laparoscopic operation. Isolation and ligation of blood vessels and bile ducts after selective liver dissection by suitable techniques are important for visual control of the operating field. Since the jet cutter has proven to give excellent clinical results in conventional liver surgery, laparoscopic liver resections with the jet cutter in six patients are carried out. Five tumors were located in the left liver lobe. There were no intra or postoperative complications. The patients were discharged from the hospital after 5 days.

Sander R (1993) presented a paper on water jet guided Nd:YAG laser coagulation - its application in the field of gastroenterology. With water jet guided laser, a comparatively new transmission system has become available, with the aid of which the laser beam is conducted from the end of the transmission fiber of the conventional light guide system to the target tissue via a water jet. The extra costs of this modality are low. The technique is easy to apply, and is associated with a number of technical advantages, such as absence of smoke and carbonisation, reduction in organ distension, etc. The water jet guided laser brings about volume coagulation in the deeper layers of the wall, with concomitant oedema and hyperaemia in the periphery. In a randomised, prospective controlled study, 89 patients with gastroduodenal ulcers bearing a visible vessel were treated with the ND:YAG laser, 43 with the non contact, and 46 with the Water jet guided modality. In the water jet group a smaller number of bleedings were induced and fewer failures, emergency operations and deaths occurred. The technical advantages of the method, together with the results of treatment in 20 tumor patients with adenomas and adenocarcinomas in the colorectum with readily achievable tumor debulking or complete eradication, suggests that the use of the water jet guided laser might also be appropriate for the treatment of tumors.

2.3 Finite Element Analysis in Soft Tissue Mechanics

G. C. Lee and N.T. Tseng (1982) have talked about finite element analyses in soft tissue mechanics.

Finite element analysis in soft-tissue mechanics must be viewed somewhat differently from its application in traditional structural mechanics research. One of the many characteristics is that the normal responses of soft tissue cannot be uniquely defined. There is always a range in magnitude of pressure or deformation of the tissue that is considered to be normal. This contributes to the difficulty in assessing accuracy in analytical solution procedures. A second distinct feature in soft tissue mechanics is the simultaneous consideration of mechanical, electrical, and biochemical responses, particularly at the microscopic level. Finite element formulations in this regard must be considerably broadened, from those that are typically used in structural mechanics research. Additionally, the experimental data available on soft tissue are generally limited. Even for those tissues where data are available, there are often more questions than answers in the conditions and limitations of the data. In most cases the difficulties of experimental observations overwhelm the desirability of the form of data for theoretical purposes. This has considerably elevated the complexity of analytical solutions which are dictated by what is given. In finite element analysis, the same is true. On the other hand, it may be said that finite element analyses are the most powerful tools available to obtain many quantitative descriptions of the behavior of soft tissue that could not be realized otherwise. Finite element analysis in man-made systems is often the means to a satisfactory solution for a problem. In biological systems its role is to provide a quantitative basis for a renewed study of the same problem in an evolving fashion.

Soft tissue may be considered in several basic categories: soft connective tissues (lung tissue, skin, blood vessels, ligaments, tendons, mesentery, and other membranes), muscles, organs, and the brain. Other than the brain most soft tissues are composites of several mechanically and biochemically different constituents. The mechanics of soft tissue, therefore, largely depend upon the individual responses and the quantitative description of the proportion and the disposition of these basic constituents.

The most fundamental type of basic component in soft tissue are the elastic fibers. They are the major force bearing components of the tissue. Elastic fibers may be considered as passive elements. The most notable are the elastins and collagens. The mechanical characteristics and the disposition of these fibers are quite different. They form as bundles in the tendon, as plane matrices in membranes, or as spatial frameworks embedded in proteins and other biological solids in lung. They typically possess the following characteristics when considered as continuum.

The force-deformation relationship of various soft tissues are always non-linear with extension ratios ranging between 10% and over 100% under different loading conditions. In typical two-dimensional modeling of membranes, skin, or blood vessels, material incompressibility is generally assumed. In certain three-dimensional models such as lung parenchyma, principles of compressible continua have been used. In most cases the material has been assumed to be homogenous and initially isotropic. Some attempt to include directional response has been made in the study of two-dimensional structures such as the skin, by assuming transverse isotropy.

Mechanics of soft tissue contains a broad spectrum of problems ranging from the standard structural analysis type to integrated study of mechanical and biochemical properties. In other words, in certain problems the assumption of a hyperelastic continuum can reasonably be made while in others, the non conservative characteristics must be properly taken into consideration.

Summary of their paper is that finite element analysis has a significant role in soft-tissue mechanics, particularly when it is coordinated with experimental research. One important new emphasis in finite element modeling is to consider its applications in very small microscopic dimensions where mechanical, electrical, and biochemical responses must be considered.

An example of finite element analysis of lung tissue conducted by the authors suggests that it is the only approach by which some quantitative estimation of the lung deformation can be obtained. An important role of finite element analysis in soft-tissue mechanics in the immediate future is to enable us to obtain quantitative input to facilitate continued experimental and numerical research efforts.

2.4 Limitations

The papers reviewed shows that there are limitations on the treatment of the injuries caused by water jet because of the unawareness of the operating conditions of the water jet in the clinical side. The following lacunae are observed.

1. The clinical material is limited in treating the types of cut under different pressures of Water jet.
2. There are limited amount of work done in finite element analysis of soft tissue especially in finite element analysis of skin.
3. The mechanical properties of different layers of skin are very limited according to the environmental conditions and all the material data are not available.
4. There are no information on how the skin will effect under different pressures of Water jet and what is the minimal pressure that will cause the shear of the skin.

The papers reviewed also show that water jet is used to do the surgery. They are used to remove tumors, blood clots with special kind of equipment. Research is going on to use water jet in surgeries and whether it is safe or unsafe. Due to less number of experimental studies there are not much data available to say that its safe.

CHAPTER 3

OBJECTIVES AND PROCEDURES

The objective here is to carry out a computational study using finite element method to observe and find the effects of water jet pressure on the skin. Since the skin is a composite material consisting of various layers and biomaterials, each having individual mechanical properties therefore to study the effect on each layer it is necessary to obtain the complete set of data.

The first step of the experiment will be to create a good representative finite element skin model and next step should be to do the linear and nonlinear static analysis of the skin model under different pressures.

The main objective is to find out that what pressure of water jet will make a cut on the skin layer and also to study the behavior of the skin layers at increasing pressures. This analysis will provide information about the extent of injury by knowing the operating pressure which caused the injury. On the other hand it will provide vital information on surgical side i.e. under what operating conditions water jet can be used as a surgical tool without damaging the tissues. By controlling the parameters the depth of cut can be adjusted i.e. up to which layer of skin surgery is required.

The procedures to fulfill the required objective are as follows.

- To obtain the available data about the mechanical properties and structure of human skin in order to create a model.

- To create an effective finite element skin model using a finite element analysis package (NISA).
- To get a good representative model of human skin and defining all the material properties of different constituents of the skin layer.
- To define the boundary conditions of the model and to apply different pressures on the surface of the model.
- To perform linear static and nonlinear static analysis of the model under different operating pressures.
- To evaluate the effect of pressures on the layer of skin and to get the required pressure that will cause the shear to happen.

CHAPTER 4

PROPOSED METHODOLOGY

The proposed methodology includes the study of operating parameters of water jet cutting, structure and mechanical properties of skin components, finite element method and finite element analysis software NISA.

4.1 Water Jet and its Operating Parameters

Water jet cutting is used to cut non metallic materials: kevlar, glass epoxy, graphite, boron, fiber-reinforced plastic, corrugated board, leather, and many others. Brittle materials, such as glass, are unsuitable in most cases for WJC because they crack or break during processing. Soft and friable materials can be easily cut using WJC and will yield good edge quality.

WJC has the following advantages over conventional cutting methods.

1. Because of point cutting, WJC is able to cut materials in almost any pattern.
2. Workpiece material loss due to machining is minimal. This is especially advantageous if the material is extremely expensive.
3. Regardless of the softness of the material, there is no crush or deformation as is likely to occur with conventional blade cutting. WJC will not burn surfaces or produce a heat-affected zone.

4. There is no environmental pollution, such as dust suspended in the air, because the water jet drains any dust simultaneously when cutting.
5. WJC can be automated easily because it is a non-contact process. (The nozzle does not touch the work.)

Table 4-1 Sample cutting conditions for WJC.

MATERIALS	THICKNESS (mm)	NOZZLE DIA (mm)	PRESSURE ksi (MPa)	FEED RATE (mm/s)
Leather	2.2	0.2	**294**	330
Vinyl Leather	0.7	0.2	**245**	500
Synthetic Rubber	1.5	0.2	**196**	830
Vinyl Chloride	3	0.2	**294**	8
Polyethylen	3.6	0.2	**196**	100
Polyster	2	0.2	**431**	2500
Kevlar	3	0.2	**294**	50
Graphite	2.3	0.2	**294**	80
Urethane	2.5	0.2	**294**	170
Glass Wool	25	0.2	**98**	167
Ceiling Board	9	0.2	**196**	2330
Gypsum Board	10	0.2	**196**	100
Cement Asbestos	18	0.2	**392**	17
Rock Wool	100	0.2	**294**	830
Corrugated Board	7	0.2	**255**	3300
Paper Board	1	0.2	**245**	8330
Pulp sheet	2	0.2	**196**	2000
Press Board	0.5	0.2	**294**	2500
Plywood	6	0.2	**294**	17
Sponge cake	60	0.2	**294**	167
Butter	50	0.2	**294**	8

4.1.1 Operating Principles

Many variable affect the performance of WJC: nozzle orifice diameter, water pressure, cutting feed rate, and standoff distance. Generally, high cutting quality would be the result of the following conditions: high pressure, large nozzle orifice, low feed rate, and narrows standoff distance. However tests should be run to determine the most productive levels and combinations of the various parameters.

Water jet machining has a variety of variable which interdependently determine the operating parameters of the cutting process. These variables can be divided, based on system components, into four categories which are listed in the Table 4-2.

Table 4-2 Water jet cutting parameters.

Hydraulic Intensifier	**Nozzle**	**Workpiece characteristics**	**Process characteristics.**
a. intensifier efficiency	a. nozzle structure	a. material hardness	a. traverse (feed) rate
b. horse power	b. nozzle diameter	b.material consistency	b. depth of cut
c. oil pressure	c. type of orifice	c. material thickness	c. width of cut
d. area of oil piston	d. orifice diameter		d. flow rate of water jet
e. pressure ratio	e. stand off distance		

The mechanic of water jet machining is illustrated in figure 4-1, and can be described as follows.

1. A hydraulic intensifier increases the pressure of Water. The pressure ratio between the oil inlet pressure (P_{01}) and the water outlet pressure (P_{w2}), r_p, is inversely proportional to the area of oil (A_0) and the water piston (A_w), respectively, i.e.

$r_p = P_{w2} / P_{01} = A_0 / A_w$

The flow rate, Q_1 , is then determined by the horse power HP ,and the efficiency η_i of the intensifier;

$Q_1 = HP \cdot \eta_i / P_{w2}$

The water velocity V_1, assuming there is no friction, is equal to ;

$V_1 = Q_1 / A_w$

2. A nozzle converts the high pressure water to a high velocity jet. There are, basically two basic approaches for water jet nozzle design: Straight taper and exponential taper. water flow from a nozzle to the atmosphere is affected by both the area and the shape of the orifice. Different orifice types and typical values of discharge C_d, velocity C_v, contraction C_c and loss coefficients ke for water orifices, are given in Table 4-2. the flow rate from the orifice Q_2 is;

$Q_2 = C_c A_r V_2$

Where $A_r = d_r^2 / 4$ [d_r is the orifice diameter]

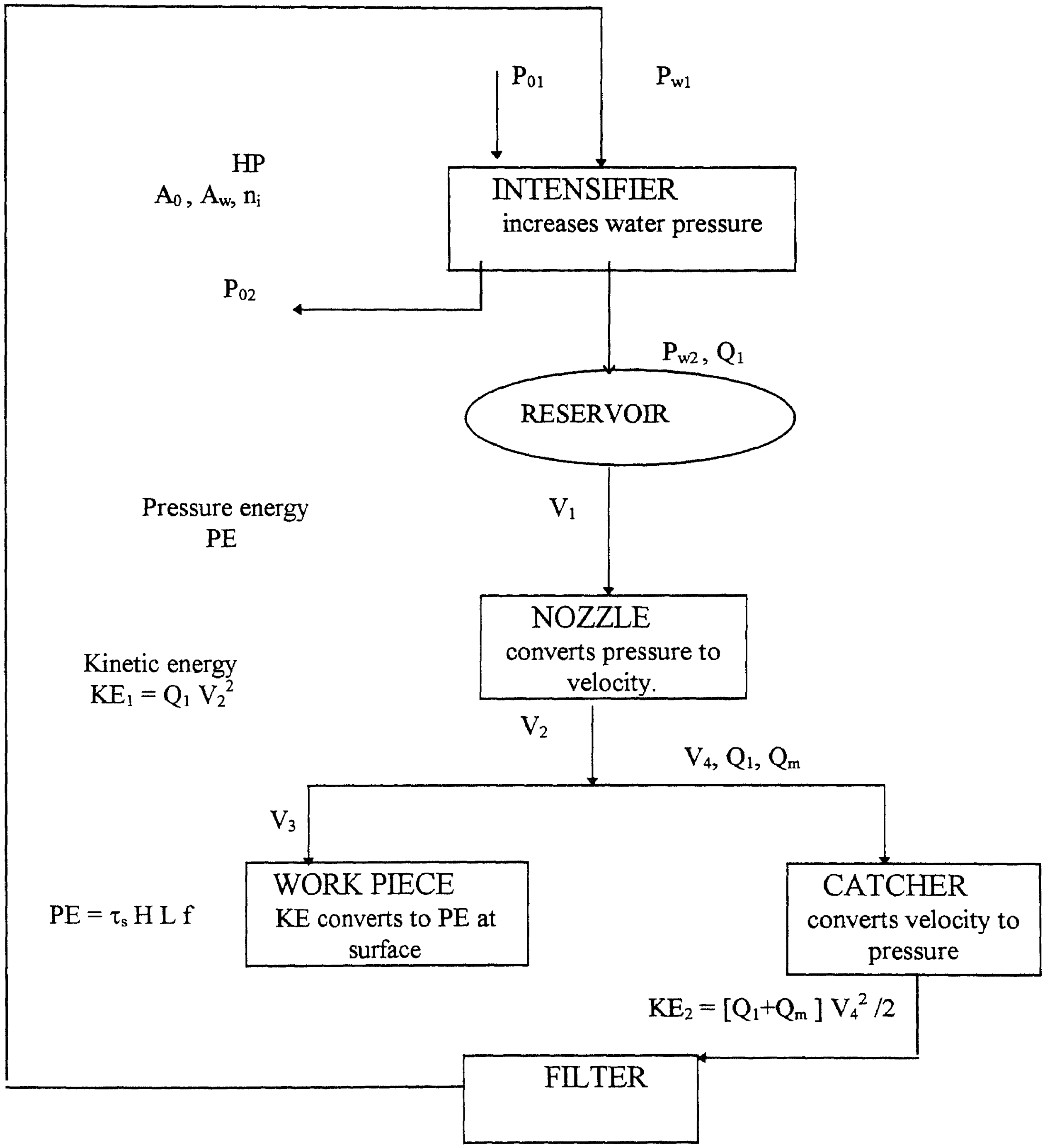


Figure 4-1 The mechanics of water jet machining.

The jet stream coming out of the nozzle possesses a kinetic energy, KE_1;

$KE_1 = k_e Q_2 V_2^2 / 2$

3. A cutting process in which most kinetic energy of the water is converted in to pressure energy when striking the surface of the workpiece. The width of cut, W, and the jet velocity, V_3, control the stand off distance between the nozzle and the workpiece, according to the following equations;

$W = d_r e^{ax}$

$V_3 = V_2 e^{-ax}$

Where x is the stand off distance, and a is the taper index which can be determined by experimental results.

The total energy, E_c, required to cut the workpiece, can be calculated as follows;

$E_c = \tau_s Q_m$

$Q_m = H L f$

Where τ_s is the shearing stress of the workpiece material, H is the depth of cut, L is the length of cut and f is the traverse (feed) rate.

4. A catcher to minimize the process noise. The water jet removes material at a rate Q_m. Thus, the total flow rate Q_2, going to the catcher is;

$Q_3 = Q_2 + Q_m$

The remaining kinetic energy, KE_2, which is not absorbed by the cutting process, is;

$KE_2 = Q_3 V_4^2 / 2$

where V_4 is the reduced velocity of the jet that exits the workpiece.

Table 4-3 Types of orifices and their coefficients values.

ORIFICE	DESCRIPTION	C_D	C_V	C_C	K_e
A	Sharp-edged	0.62	0.98	0.63	0.08
B	Round-edged	0.98	0.98	1.0	0.10
C	Tube with square-edged	0.61	0.61	1.0	0.51
D	Short tube with rounded entrance	0.54	0.99	0.55	0.15

4.2 Structure and Mechanical Properties of Skin

Skin is a vital organ, in the sense that loss of a substantial fraction of its mass immediately threatens the life of the individual. The primary function of skin is to act as a buffer state between the body and the world outside.

Four types of tissue can be distinguished clearly in normal skin. The epidermis, outside, is a 0.1 mm thick sheet, comprising about 10 layers of keratinocytes at levels of maturation which increase from the inside out. The dermis, inside, is a 2 - 5 mm thick layer of vascularized and innervated connective tissue with very few cells, mostly quiescent fibroblasts. The dermis is a massive tissue, accounting for 15 - 20 % of the total body weight. Interleaved between the epidermis and the dermis is the basement membrane, an approximately 20 nm thick multilayered membrane. A fourth layer, the subcutis, underneath the dermis and 0.4 - 4 mm in thickness, comprises primarily fat tissue. In addition to these basic structural elements, skin contains several appendages (adnexa), including hair follicles, sweat glands, and sebaceous glands. The latter are mostly embedded in the dermis, although they are ensheathed in layers of epidermal tissue.

The measurement of thickness of the skin folds are made at certain standard locations over the body surface. A fold of skin is elevated by gentle pinching, and its thickness is measured using calipers especially designed to close upon the skin with a standard force controlled by a spring. The validity of the method is based upon the assumption that fat is stored within the skin in proportion to its storage elsewhere in the body. These judgments are based upon averaged data and do not mean that in any given subject the skin fold thickness will reveal subtle changes in bodily fat content. Absolute skin fold thickness at different sites are given in the following table.

Table 4-4 Skin thickness at different sites.

SKIN FOLDS	THICKNESS MEASUREMENTS in mm
Abdomen	18.6
Chest	14.5
Arm	12.5
Calculated fat content	12.4

4.2.1 Mechanical Role of the Skin Components

Collagen fibers are the major mechanical elements in the skin. When these fibers are stretched, their effects predominate over those of all the other components. They are strong (tensile strength of 5 to 15 x 10^2 MPa) and stiff (Young's modulus in the linear region is approximately 1 GPa), and they stretch reversibly up to 2 to 4 percent. In the native state they are viscoelastic. Thermodynamic studies [14] have revealed that collagen behaves like a crystalline rather than a rubberlike material.

Elastin is considerably less stiff than collagen but can be reversibly stretched to more than 100 percent. Its elastic properties are related to configurational entropic changes as in rubber like materials. On the basis of mechanoenzymatic studies [14], mechanohistological observations, and comparative mechanical data, it is apparent that the elastin fibers are the first to be strectched when the tissue is strained. Their effect on the response of the whole skin is thus significant at low levels of strain when the collagen fibers are still crimped. The notion is further strengthened by thermomechanical data which show that at low strain levels skin has a negative thermal expansion coefficient while at higher strain levels it is positive as in collagens.

The role of ground substance matrix in the response of the skin to tension is not yet clear. Studies [15] on the effects of temperature and humidity on the spectrum of relaxation times in very low strain levels show similar responses of skin to that of gels consisting of hyaluronic acid and water. This suggests that the ground substance is responsible for the viscoelastic behavior in this low strain range. It was also suggested that the fluidlike ground substance exudates from the interfiber space while the fibers become reoriented and densely packed upon stretch. This flow of ground substance may be associated with the viscous part of the skin's behavior, primarily in the toe region (the nonlinear region of the stress strain curve), in which the collagen fibers are not yet fully aligned and stretched.

There exists, however, other evidence which suggests a lesser significance of the matrix. Study of the in vitro response of rat skin in which the hyaluronic acid (regarded as the predominant mechanical component in the groud substance) was differentially digested revealed little effect of the same treatment on the rate of creep in torsional tests on human skin in vivo. Daly [14] found that in the initial reorientation phase (in which the migration of collagen fibers is thought to squeeze the fluid away), the response of the skin is approximately elastic. The viscous effect is highest at the final region when the collagen fibers are closely packed and straight.

Compressive tests [14] of the skin (indentometry and skin fold compressibility) show significant effects of the ground substance. The speed of compression, the amount of expressible fluid, and the skin's permeability all increase upon application of hyalurondase. These effects are thought to be related to the water affinity of the matrix mucopolysaccharides.

The epidermis contributes little to the skin's resistance to stretch, but its contribution to the frictional resistance of the skin is predominant. Its effect on the compressive indentation response of the skin is not clear. Some mechanical properties of the skin components are listed in the Table 4-5.

Table 4-5 Mechanical properties of some components of skin.

BIOMATERIAL	THICKNESS mm	STRENGTH MPa (N/mm^2)	Poissons Ratio	YOUNG'S MODULUS MPa (N/mm^2)
Skin (theoretical)	6.4 - 8.8	15		35
Epidermis	0.1	100 (low humidity) 10 (wet state)	0.2	1000
Basement membrane	0.02×10^{-3}	90		
Dermis	2 - 5	5	0.2	100
Subcutic (fat tissue)	0.4 - 4	2	0.2	50
Collagen		50	0.2	1000

4.3 Finite Element Method

The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Although originally developed to study the stresses in complex airframe structures, it has since been extended and applied to the broad field of continuum mechanics. Because of diversity and flexibility as an analysis tool, it is receiving much attention in engineering schools and in industry.

In more and more engineering situations today, it is necessary to obtain appropriate numerical solutions to problems rather than exact closed form solutions. For example, to find the load capacity of a plate that has several stiffeners and old shaped holes, the concentration of pollutants during nonuniform atmospheric conditions, or the rate of fluid flow through a passage of arbitrary shape. The governing equations and boundary conditions for these problems can be written. The difficulty in these examples lies in the fact that either the geometry or some other feature of the problem is irregular or "arbitrary". Analytical solutions to problems of this type seldom exist; yet these are the kinds of problems that engineers and scientists are called upon to solve.

The resourcefulness of the analyst usually comes to the rescue and provides several alternatives to overcome this dilemma. One possibility is to make simplifying assumptions to ignore the difficulties and reduce the problem to one that can be handled. Sometimes this procedure works; but, more often than not, it leads to serious inaccuracies or wrong answers. Now that large scale digital computers are widely available, a more viable alternative is to retain the complexities of the problem and try to find an approximate numerical solution.

Several approximate numerical analysis methods have evolved over the years, the most commonly used method is the general finite difference scheme. In addition to the finite difference method, another, more recent numerical method known as finite element method has emerged. Unlike the finite difference method, which envisions the solution region as an array of grid points, the finite element method envisions the solution region as built up of many small, interconnected subregions or elements. A finite element model of a problem gives a piecewise approximation to the governing equations. The basic premise of the finite element method is that a solution region can be analytically modeled or approximated by replacing it with an assemblage of discrete elements. Since these elements can be put together in a variety of ways, they can be used to represent exceedingly complex shapes.

The finite element model gives a better approximation to the region and requires fewer nodes. Also, a better approximation to the boundary shape results because the curved boundary is represented by a series of straight lines. The finite element method is well suited for problems with complex geometries.

In a continuum problem of any dimension the field variable possesses infinitely many values because it is a function of each generic point in the body or solution region. Consequently, the problem is one with an infinite number of unknowns. The finite element discretization procedures reduce the problem to one of a finite number of unknowns by dividing the solution region in to elements and by expressing the unknown field variable in terms of assumed approximating functions within each element. The approximating functions are defined in terms of the values of the field variables at specified points called nodes or nodal points. Nodes usually lie on the element boundaries where adjacent elements are considered to be connected. In addition to boundary nodes, an element may also have a few interior nodes. The nodal values of the field variable and the interpolation functions for the elements completely define the behavior of the field variable within the elements. For the finite element representation of the problem the nodal values of the field variable become the new unknowns. Once these unknowns are found, the interpolation functions define the field variable throughout the assemblage of elements.

Clearly, the nature of the solution and the degree of approximation depend not only on the size and number of the elements used, but also on the interpolation functions selected. As one would expect, we cannot choose functions arbitrarily, because certain compatibility conditions should be satisfied. Often functions are chosen so that the field variable or its derivatives are continuous across adjoining element boundaries. An important feature of the finite element method is the ability to formulate solutions for individual elements before putting them together to represent the entire problem. This means, for example, that if we are treating a problem in stress analysis, we can find the force displacement or stiffness characteristics of each individual element and then assemble the elements to find the stiffness of the whole structure. In assence, a complex problem reduces to considering a series of greatly simplified problems.

Another advantage of the finite element method is the variety of ways in which one can formulate the properties of individual elements. There are basically four different approaches. The first approach to obtaining element properties is called the direct approach because its origin is traceable to the direct stiffness method of structural analysis. Although the direct approach can be used only for relatively simple problems, it also suggests the need for matrix algebra in dealing with the finite element equations.

Element properties obtained by the direct approach can also be determined by the more versatile and more advanced variational approach. The variational approach relies on the calculas of variations and involves extremizing a functional. For problems in solid mechanics the functional turns out to be the potential energy, the complementary potential energy, or some derivative of these, such as the Reissner variational principle. Knowledge of the variational approach is necessary to work beyond the introductory level and to extend the finite element method to a wide variety of engineering problems. Whereas the direct approach can be used to formulate element properties for only the simplest element shapes, the variational approach can be employed for both simple and sophisticated element shapes.

A third and even more versatile approach to deriving element properties has its basis entirely in mathematics and is known as the weighted residuals approach. The weighted residuals approach begins with the governing equations of the problem and proceeds without relying on a functional or a variational statement. This approach is advantageous because it thereby becomes possible to extend the finite element method to problems where no functional is available. For some problems we do not have a functional - either because one may not have been discovered or because one does not exist.

A fourth approach relies on the balance of thermal and/or mechanical energy of a system. The energy balance approach requires no variational statement and hence broadens considerably the range of possible applications of the finite element method.

Regardless of the approach used to find the element properties, the solution of a continuum problem by the finite element method always follows an orderly step-by-step process.

There are different analyses which can be done using the finite element method, the linear static and nonlinear static analysis are described below.

4.3.1 Linear Static Analysis

Linear static analysis is concerned with the linear behavior of elastic continua under prescribed boundary conditions and statically applied loads. This includes the calculation of displacements, strains, stresses, reactions, and energy in the continua. In general, the applied loads include prescribed forces and pressures. Other loading types may also be included, namely body forces (e.g., gravity and centrifugal loads) and displacements, coupled displacements, multi-point constraints and rigid link specifications. The basic equation for linear static analysis may be written in the form

$$K\,u = p$$

Where K is the linear stiffness matrix of the structure, u is the nodal displacement vector and p is the load vector.

4.3.2 Nonlinear Static Analysis

Nonlinear static analysis deals with nonlinear behavior of structures under static loading. The nonlinearities considered may be material, geometric, or combined nonlinearity. In material nonlinearity, the material constitutive, or stress-strain, relations may be dependent on stresses, strains and/or displacements. Applications for material nonlinearity are evident, for example, in plasticity, creep, and viscoelasticity problems. Three main material nonlinear behaviors are : the elastoplastic material behavior, creep, and the hyperelastic or rubber-like material behavior. In the elastoplastic material behavior various types of yield criteria and hardening rules are available. In creep model, both general and Oak Ridge National Laboratory material laws can be used. In the hyperelastic or rubber-like material models, various types of strain energy functions with finite compressibility or near incompressibility behavior are available.

In combined geometric and material nonlinearities, a distinction has to be drawn between the original and the deformed configurations of the structure, and the equilibrium or energy balance equations must be written for the deformed configuration. Consequently various formulations, and stress and strain measures arise depending on the chosen reference configuration to describe the deformation of the body. Two referential formulations are generally available. These are: the total and the updated Lagrangian formulation. The total lagrangial formulation uses a fixed configuration as a reference to describe the motion of the body. In updated Lagrangian formulation, the reference configuration is always updated. The second Piola-Kirchhoff stress tensor and the Gree-Lagrangian strain tensor may be used in either formulation.

Both formulations are equivalent mathematically and they include all the nonlinear kinematic effects. If appropriate constitutive relations are used, and the same approximations are introduced, identical results should be obtained. The advantage of one formulation over the other may be in numerical efficiency, ease of handling particular nonlinear boundary conditions, ease of specifying material constitutive relations, etc.

4.4 NISA (Finite Element Analysis Software)

The finite element analysis of the skin model is done using EMRC's NISA (Numerically Integrated Elements for System Analysis) software. The construction of skin model is made using EMRC'S DISPLAY.

DISPLAY is an interactive, user friendly processor for modeling and results analysis. It has been developed so that the same program is available on PC, workstation, super-mini and mainframe computer systems. This allows for easy transfer of models from one system to another.

DISPLAY gives the engineer and the analyst an extremely powerful and cost-effective modeling tool for finite element and mechanism analysis. Post-processing is integrated in DISPLAY. It is designed to save time and money through the use of advanced techniques and computer aided engineering methods at the leading edge of technology.

DISPLAY is highly integrated with the NISA family of analysis software so that the user can utilize the diverse capabilities by only one program with the NISA family.

4.5 Modules of Modeling/Analysis

4.5.1 Geometric Modeling

The first step in the process of analyzing an object or process is to capture the geometry of the objects involved. This consists of a mathematical description of the boundary and interior of the object. To achieve this, DISPLAY provides facilities to define locations in space (called GRIDS), straight or curved line segments (called LINES), surfaces (called PATCHES) and solids (called HYPERPATCHES). All the above are referred as geometric entities.

4.5.2 Meshing Modules

Once the geometric domain of the object or model is described, the next step consists of discretizing this domain to define a mesh of nodes and elements. There are variety of operations in DISPLAY that accomplish Finite Element Generation called meshing or fegging.

Fegging can be done manually on each geometric entity, resulting in maximum user control over the resultant mesh, or the complete geometric model may be meshed automatically by the automatic meshing capabilities of DISPLAY. Next, the boundary conditions of the model in terms of loads, constraints, etc. need to be applied to complete the simulation of the real life object with the model.

4.5.3 Model Verification

While modeling or after the model is complete, DISPLAY allows a host of operations for verifying and checking the model. These range from sophisticated checks for distortion, warping, skewness, etc. of elements that produce numeric output to graphic checks that visually highlight boundary conditions as well as potential discontinuities in the finite element model, for example, loads, pressures, constraints, etc. can all be graphically plotted for visual verification.

4.5.4 Analysis Modules

DISPLAY directly interfaces with the NISA family of general purpose analysis programs. This means that DISPLAY can write a file containing all the model and analysis directives required in a format acceptable to NISA as well as read a file output by NISA containing the results of an analysis run.

NISA II is the parent program of the NISA family. It is general purpose finite element analysis program for structural and heat transfer analysis. A wide range of analysis capabilities are available including:

Linear static analysis

Nonlinear static analysis

Linear direct transient analysis

Eigenvalue analysis

Modal dynamic analysis including transient dynamic, random vibration, frequency response and shock spectrum analysis.

Buckling analysis

Steady state and transient heat transfer analysis.

4.5.5 Post Processing

Graphical representation and manipulation of the results may be performed interactively using the DISPLAY postprocessing module. A brief account of the major post processing features available in the DISPLAY is outlined below:

Deformed geometry plots, separate or superimposed on undeformed geometry.

Contour plots of displacements, stresses, strains and temperatures.

Unaveraged element stress contours including error estimates.

Contour plots of cut sections for 3D models.

Layer stresses for composite elements.

Animated deformed and modal shapes on creation graphics devices.

The finite element analysis results include the followings:

UX Displacements in X- direction.

UY Displacements in Y- direction.

UZ Displacements in Z - direction.

URES Resultant displacement SQRT (UX*UX + UY*UY + UZ*UZ).

ULIN Linear displacement UX*FACT(1) + UY*FACT(2) + UZ*FACT(3).

SXX Stress in X-X direction (axial).

SYY Stress in Y-Y direction (axial).

SZZ Stress in Z-Z direction (axial).

SXY Stress in X-Y direction (axial).

SYZ Stress in Y-Z direction (axial).

SXZ Stress in X-Z direction (axial).

S1P First Principle stress.

S2P Second Principle stress.

S3P Third Principle stress.

SEQ1 Maximum shear stress.

SEQ2 Von Mises stress.

SEQ3 Octahedral stress.

CHAPTER 5

CASE STUDY AND RESULTS

It is important to note that results one obtains using the finite element method are approximate to the physical system which is represented by a discrete mathematical model. The physical system has an infinite number of degrees of freedom. The degree of the approximation in the calculated results depends on how closely the physical system is modeled. The modeling process involves many possibilities: the element types and shapes, the number of elements used and the mesh grading, the material and geometric properties and the applied loads and boundary conditions. Each of these factors may lead to the misrepresentation of the actual physical system and may provide inaccurate results for the physical problem.

5.1 Assumptions

Before the construction of finite element model, some assumptions were made, which were as follows:

1. Only three layers of skin have been modeled that are dermis, epidermis and subcutis.
2. It is assumed that the adjacent layers are connected together with some gap elements. The gap elements used here are given the properties of water.
3. The lower four nodes of the subcutis is assumed to have no displacement in any direction.

4. Collagen fibers are assumed to be tied up with other skin layers in random.
5. The pressure loading is assumed to be at the top center surface of the epidermis.
6. The young modulus values of the dermis and subcutis are assumed to be lower than the epidermis, which are listed in Table 4-5.
7. The poisson ratio of the elements used are assumed to have a value of 0.2.

5.2 Construction of Finite Element Skin Model

The modeling of a physical problem may be divided into two stages:

Geometric modeling or representation.

Finite element modeling.

5.2.1 Geometric Modeling

The procedures for creating a geometric model of the skin are as follows:

1. The geometric entities is created using the solid primitives command. Three cubes are created one after the other with gaps. The first cube of identity number 1 has the dimensions of 1mm length in x direction, and 1 mm length in y direction with height of 0.4 mm in z direction, which is the thickness of subcutis (fat tissues connected from the bones) and the center i.e. as a reference point at (0,0,0). The second cube of identity number 2 has the dimensions of 1mm length in x direction, and 1 mm length in y direction, with height of 2.0 mm in z direction which is the thickness of dermis and the center at 0,0,1.225, creating a gap of 0.025 mm between the two adjacent cubes. The third cube of identity number 3 has the dimensions of 1mm length in x direction and 1 mm length in y

direction with height of 0.1 mm in z direction which is the thickness of epidermis and the center at (0,0,2.295), leaving a gap of 0.025 mm between the two adjacent cubes. See Figure 5-2 for reference.

2. After creating the cubes the next step is to define the patches and hyperpatches. For this create patches from the existing primitive cubes by giving the identity numbers of cubes, the software will automatically generate the patches. Similarly extract hyperpatches from the existing primitive cubes.

This completes the geometric modeling of the skin model.

5.2.2 Finite Element Modeling

General purpose finite element packages include a large number of different, fluid flow and heat transfer elements which are developed for specific applications.

The selection of element for an application should be based on its capabilities, its cost (stiffness matrix generation, decomposition and stress calculation, etc.) and the desired accuracy in the results.

Elements should be of regular shapes as much as possible. This can be achieved when the element aspect ratio is close to unity. The best shape of a quadrilateral is a square, and that of a hexahedron is a cube. The distortion index, calculated by DISPLAY, is the indicator of how well the element maps to the ideal or the best shape of that element. The ratio of the minimum Jacobian to the average Jacobian is defined as the distortion index. The most desirable distortion index is 1.0, which indicates that element maps perfectly to the ideal shape.

To accomplish the above objectives the elements selected to define different components of the skin model are listed in the Table 5-1.

Table 5-1 Summary of structural elements used to create the model.

SKIN LAYER TYPE	ELEMENT TYPE NO. (NKTP)	ELEMENT DESCRIPTION	NO. OF NODES (NORDR)	DOF PER NODE
EPIDERMIS	4	3-D SOLID	4 - 20	3
DERMIS	4	3-D SOLID	4 - 20	3
SUBCUTIS	4	3-D SOLID	4 - 20	3
GAP B/W ADJACENT LAYERS	50	3-D GAP / FRICTION ELEMENT	2	3
COLLAGEN FIBERS	14	3-D SPAR	2	3

NKTP is the stiffness type used in the NISA's element library.

The maximum amount of time, in finite element analysis, is spent on generating elemental and nodal data. DISPLAY gives the user an option of fully automatic, semiautomatic or mapped meshing thereby reducing modeling time. Users can map or break lines, patches or hyperpatches to automatically generate nodes and elements. DISPLAY allows the user to generate nodes and elements automatically at the same time allowing control over size and number of elements.

For the generation of three dimensional elements, FEG option is used. The three cubes i.e. epidermis, dermis and the subcutis tetrahedron type of element is used. The simplest element in three dimensions is the four node tetrahedron [18]. The tetrahedron elements satisfies the compatibility, completeness, and isotropy requirements and have better computational efficiencies [18]. Also in the literature, soft tissue mechanics of lungs [19], tetrahedron type elements are used as representative of tissues. The procedure to generate automatically the nodes and elements of the required types are described below.

For the first cube, from the FEG option, select type tetrahedron and then input hyperpatches identity number created previously. After defining the hyperpatches ID next step is to define the E1/E2/E3 values which are the number of elements in the u, v and w parametric direction, respectively. The values selected here are 5/5/5 for the purpose of precise results. After this NKTP type has to be defined which is 4 for the 3-D solid elements, and NORDR i.e. order of these elements which is 20. After defining all the above parameters, material identity number and the property identity number has to be defined. All the data are same for the remaining hyperpatches of the cubes but the first cube hyperpatches, i.e. subcutis, is given material ID number 1 and property ID number 1, the second cube hyperpatches, i.e. dermis, is given material ID number 2 and property ID number 2, and the third cube hyperpatches, i.e. epidermis, is given material ID number 3 and property ID number 3.

The above explained step generates the elements and nodes. In order to have approximate results it is important to focus on a small sectional part of the skin , therefore only one element in the v direction was selected to do the analysis and the rest of four elements were deleted in the v direction in order to reduce the degrees of freedom. The model is shown in the Figure 5-2.

```
NUXY,    1,0, 2.00000E-01,
NUXZ,    1,0, 2.00000E-01,
NUYZ,    1,0, 2.00000E-01,
DENS,    1,0, 5.50000E-06,
EX ,     2,0, 1.00000E+02,
EY ,     2,0, 1.00000E+02,
EZ ,     2,0, 1.00000E+02,
NUXY,    2,0, 2.00000E-01,
NUXZ,    2,0, 2.00000E-01,
NUYZ,    2,0, 2.00000E-01,
DENS,    2,0, 8.00000E-06,
EX ,     3,0, 1.00000E+03,
EY ,     3,0, 1.00000E+03,
EZ ,     3,0, 1.00000E+03,
NUXY,    3,0, 2.00000E-01,
NUXZ,    3,0, 2.00000E-01,
NUYZ,    3,0, 2.00000E-01,
DENS,    3,0, 1.05600E-05,
EX ,     4,0, 1.00000E+03,
EY ,     4,0, 1.00000E+03,
EZ ,     4,0, 1.00000E+03,
NUXY,    4,0, 2.00000E-01,
NUXZ,    4,0, 2.00000E-01,
NUYZ,    4,0, 2.00000E-01,
DENS,    4,0, 1.80000E-05,
NUXY,    5,0, 2.00000E-01,
*TIMEAMP
333,1,0
1.0,1.0
*EVENT, ID = 1
INCREMENTS = EQUAL,10
TIMEATEND = 1.0
MAXITERATIONS = 10
TOLERANCES = .1E-03,.1E-03,.1E-03
*SPDISP
** SPDISP SET =     1
    1,UX  , 0.00000E+00,,,,,,,,    0
    1,UY  , 0.00000E+00,,,,,,,,    0
    1,UZ  , 0.00000E+00,,,,,,,,    0
    6,UX  , 0.00000E+00,,,,,,,,    0
    6,UY  , 0.00000E+00,,,,,,,,    0
    6,UZ  , 0.00000E+00,,,,,,,,    0
    7,UX  , 0.00000E+00,,,,,,,,    0
    7,UY  , 0.00000E+00,,,,,,,,    0
    7,UZ  , 0.00000E+00,,,,,,,,    0
   12,UX  , 0.00000E+00,,,,,,,,    0
   12,UY  , 0.00000E+00,,,,,,,,    0
   12,UZ  , 0.00000E+00,,,,,,,,    0
*PRESSURE, TCRV = 333
** PRESSURE SET =     1
 2581,,,3,0, 0, .100E+02,   0
*NLOUT
1,3,0,1,0,1,0,0
*ENDDATA
```

After the finite element generation of the dermis, epidermis and the subcutis, the next step is to create the gap elements and the collagen fibers which are essential components of skin. For this the option elements, add is used. The required procedures are; from FEG option select elements, "add" and then define stiffness type for collagen fibers stiffness type 14 is used. Then element order has to be defined which is 1 for collagen fibers. After this material ID number an property ID number is defined which is 4 for the collagen fibers. The next step is connectivity, which connects two nodes to define the elements. Approximately 15 elements were created as a representative of collagen fibers.

Since it is assumed that the layers of skin are glued together, therefore it is necessary to use some gap or frictional elements in between the adjacent layers. The gap/friction elements are created between the adjacent layers of skin model by using the same above procedure as used for creating spring elements, defining the stiffness type as 50, order type as 1 and material ID number, and property ID number as 5.

This completes the representative model of skin. The next step should be to define all the boundary conditions and loading conditions. The physical schematic view of skin highlighting the epidermis, basement membrane and the dermis is shown in Figure 5-1, and the representative finite element skin model with the boundary conditions and loading is shown in the Figure 5-2.

Table 5-2 Element reference for appendix A.

Skin layer	**Element Numbers**	**Element Type NKTP**	**Material ID**	**Total Elements**
Epidermis	2462-2586	4	3	125
Gap	1420-1431 2450-2461	50	5	24
Dermis	1432-1471, 1475-1534 1536-1575, 1577-1676 1678-1897, 1899-1938 1942-2141, 2144-2203 2205-2244, 2249-2318 2320-2449	4	2	1000
Subcutis	1294-1418	4	1	125
Collagen	1419,14721473,1474, 1535,1576,1677,1898, 1939,1940,1941,2142, 2143,2204,2246,2247, 2248,2319	14	4	18

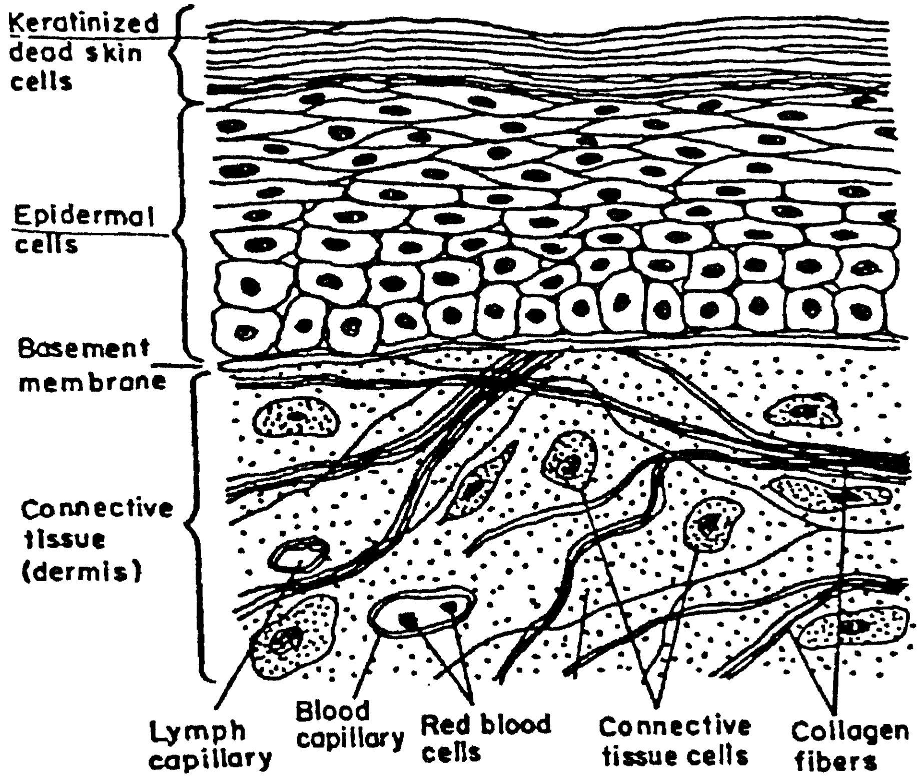


Figure 5-1 Schematic view of skin which highlights the epidermis, basement membrane and the dermis. (Small fraction of thickness of dermis is shown)

5.3 Boundary Conditions and Loading

After completion of the finite element model the boundary conditions and loading should be applied. All constraints and loads are assigned set ID. These set ID help the user to keep track of various conditions and can also be used to define the number of load cases.

DISPLAY lets the user constrain any combination of the six degrees of freedom at a node, but only in the global coordinate system. The user can define constraints either on a user defined range of nodes; or apply them to nodes on a user defined plane; or apply them to nodes on a coordinate plane of a curvilinear coordinate system.

In the skin model only four nodes have been assigned the displacement constraint. The procedure for this is to select structural option from the boundary condition menu and then displacement and add on nodes. The parameters required for this are node ID, which are four bottom corners of the skin model, set Id, which is 1 and then define the displacement value. As it is assumed that the bottom layer of skin, which is subcutis, is glued to the bone therefore no rotation or displacement in any direction will take place, hence all the values given here are zero. For reference see Figure 5-2.

DISPLAY lets the user to apply a pressure to the faces of various elements. Pressure application will be displayed as an arrow normal to the center of face of the element. Note that the solid elements have 5 or 6 faces. A concentrated pressure is applied on the center element. For this the center element of the top layer is selected and the pressure of 10 N/mm^2 is applied. The procedure for this is to select structural option from the boundary condition menu and then pressure and add on elements. The parameters required for this are element ID, which is one element on the top center of the skin model, set ID, which is 1, face number which is 3 for the top face of the tetrahedron and then define the pressure value which at the initial case is 10 N/mm^2. After defining all the necessary boundary conditions and loading, the next step is to define all the element and material properties.

5.4 Element and Material Properties

Element configuration and connectivity is defined by the nodes and their coordinates. However, some element properties such as thickness for plate or shell elements, and cross-sectional properties for beam elements have to be specified separately. Property tables for particular property set ID has to be input.

The user also needs to define the material properties for the elements. Depending on the analysis-type material properties such as, modulus of elasticity, poisson's ratio, coefficient of thermal expansion, density, etc., need to be specified. Material and property tables must be defined for each set ID which has been assigned to an element during element generation.

Since all the data is not available therefore some of the input data are based on assumption, for example the densities of the skin components and the young modulus of subcutis. The geometric properties are added through the Model data option. The procedures are; select property, add, property ID and input the required necessary property for the type of element. Similarly for the Material data, properties are added through the Model data option and then material, and add material ID. Note that the required ID sets should be same to the one defined in finite element generation. The material and geometric properties are listed in Table 4-5.

The necessary input data for the used elements and their corresponding values are summarized in the tables according to the material and property identity number used.

Table 5-3 Element reference and data used for subcutis.

Material & Property ID	**1 (Subcutis)**
Element Types	NKTP = 4, 3-D solid element
Analysis Types	Linear static, Nonlinear static
Degree of Freedom	3 per node: UX, UY, UZ
NORDR (shape/no. of nodes)	Tetrahedron: 4 nodes (NORDR = 20)
Real Constants	None
Material Properties Isotropic Elastic	EX = 50 N/mm^2 NUXY = 0.2 DENS = 5.5 E-06 Kg /mm^3

TABLE 5-4 Element reference and data used for dermis.

Material & Property ID	**2 (Dermis)**
Element Types	NKTP = 4, 3-D solid element
Analysis Types	Linear static, Nonlinear static
Degree of Freedom	3 per node: UX, UY, UZ
NORDR (shape/no. of nodes)	Tetrahedron: 4 nodes (NORDR = 20)
Real Constants	None
Material Properties Isotropic Elastic	EX = 100 N/mm^2 NUXY = 0.2 DENS = 8.0 E-06 Kg/mm^3

Table 5-5 Element reference and data used for epidermis.

Material & Property ID	**3 (Epidermis)**
Element Types	NKTP = 4, 3-D solid element
Analysis Types	Static, Nonlinear static
Degree of Freedom	3 per node: UX, UY, UZ
NORDR (shape/no. of nodes)	Tetrahedron: 4 nodes (NORDR = 20)
Real Constants	None
Material Properties Isotropic Elastic	EX = 1000 N/mm^2 NUXY = 0.2 DENS = 1.056 E-05 Kg/mm

Table 5-6 Element reference and data used for collagen fibers.

Material & Property ID	**4 (Collagen fibers)**
Element Types	NKTP = 14, 3-D spar element
Analysis Types	Static, Nonlinear static
Degree of Freedom	3 per node: UX, UY, UZ
NORDR (shape/no. of nodes)	Line: 2 nodes (NORDR = 1)
Real Constants	A1: X-sectional area at node 1 = 0.005 A2: X-sectional area at node 2 = 0.005 TENSIN: Initial tension = 0 TCKEY : Type of member = 0 for tension-compression
Material Properties Isotropic Elastic	EX = 1000 N/mm^2 DENS = 1.8 E-05 Kg/mm^3

Table 5-7 Element reference and data used for gap elements.

Material & Property ID	**5, Gap elements**
Element Types	NKTP = 50, 3-D Gap/friction element
Analysis Types	Nonlinear static
Degree of Freedom	3 per node: UX, UY, UZ
NORDR (shape/no. of nodes)	Line: 2 nodes (NORDR = 1)
Real Constants	Kn: Axial stiffens = 0.001 N/mm Kt: Tangential stiffness = 0.001 N/mm Sn: Small axial stiffens = 1 E-08 N/mm St: Small tangential stiffness=1 E-08 N/mm GW: Initial gap width = 0.025 mm
Material Properties	Coefficient of friction: NUXY = 0.2

The model is now completely defined. The NISA input file "skin.nis" of the skin model is in appendix A. Before running the model the elements distortion was checked and it was found that elements passed the distortion check showing that the elements created are in good shape, i.e. not distorted. After defining the relevant executive control commands, the model is ready for the analysis and postprocessing.

5.5 Results

The output results should be compared to available standard results, for example, experimental results, previous similar analysis, results from simplified models, and of course, engineering judgment. The stress results should not be deemed correct unless the displacement results are judged acceptable. However, note that a mesh which gives accurate displacements may be too coarse for an accurate stress prediction.

The convergence test is carried out by the software itself while running the analysis. The software checks the convergence at different iteration for each load cases. The results are saved in the output file when the convergence test is passed for the particular load case.

The results are saved as a data file which are viewed through the postprocessor. The results of the nonlinear static analysis of the skin model at 10 MPa of pressure are in appendix B.

The results from the nonlinear static analysis of material type are listed in Table 5-8 and the results from the linear static analysis are listed in Table 5-9.

Table 5-8 Results of the nonlinear static analysis .

PRESSURES MPa	X DISP mm	Y DISP mm	Z DISP mm	RESULTANT DISP mm	SXX STRESS MPa	SYY STRESS MPa	SZZ STRESS MPa	SXY STRESS MPa	SYZ STRESS MPa	SZX STRESS MPa
10	2.20	2.23	0.18	3.14	4.69	0.71	0.52	0.12	0.29	0.86
20	3.94	4.02	0.32	5.64	8.59	1.30	1.00	0.20	0.55	1.57
30	5.83	5.96	0.47	8.35	12.75	1.93	1.47	0.30	0.81	2.33
40	7.71	7.88	0.63	11.04	16.88	2.56	1.96	0.39	1.08	3.09
50	9.59	9.80	0.78	13.72	21.01	3.18	2.44	0.49	1.35	3.84
60	11.46	11.72	0.93	16.41	15.14	3.81	2.92	0.58	1.62	4.59
70	13.34	13.64	1.08	19.10	29.27	4.44	3.40	0.67	1.88	5.35
80	15.22	15.56	1.24	21.79	33.40	5.06	3.89	0.77	2.15	6.10
90	17.09	17.48	1.39	24.48	37.53	5.69	4.37	0.86	2.42	6.86
100	18.97	19.40	1.59	27.17	41.66	6.32	4.85	0.96	2.68	7.61

Table 5-8 (cont.)

PRESSURES MPa	EFFECTIVE STRESS MPa	1 PRINCIPAL STRESS MPa	2 PRINCIPAL STRESS MPa	3 PRINCIPAL STRESS MPa	MAX SHEAR STRESS MPa	VON MISES STRESS MPa
10	9.50	4.69	0.71	0.06	2.58	4.69
20	17.33	8.60	1.31	0.10	4.73	8.58
30	25.70	12.75	1.90	0.14	7.02	12.73
40	34.01	16.88	2.57	0.19	9.29	16.86
50	42.33	21.02	3.20	0.23	11.56	20.98
60	50.65	25.15	3.83	0.28	13.84	25.11
70	58.96	29.28	4.46	0.32	16.11	29.23
80	67.28	33.42	5.09	0.37	18.38	33.36
90	75.59	37.55	5.71	0.41	20.66	37.48
100	83.91	41.68	6.34	0.46	22.93	41.61

Table 5-9 Results of the linear static analysis.

PRESSURES MPa	X DISP mm	Y DISP mm	Z DISP mm	RESULTANT DISP mm	SXX STRESS MPa	SYY STRESS MPa	SZZ STRESS MPa	SXY STRESS MPa	SYZ STRESS MPa	SZX STRESS MPa
10	2.21	2.24	0.18	3.15	4.68	0.71	0.53	0.12	0.29	0.86
20	4.41	4.49	0.36	6.30	9.36	1.41	1.06	0.23	0.58	1.72
30	6.62	6.73	0.54	9.45	14.04	2.12	1.58	0.35	0.87	2.58
40	8.82	8.98	0.72	12.60	18.72	2.83	2.11	0.46	1.16	3.45
50	11.03	11.22	0.89	15.75	23.40	3.54	2.64	0.58	1.45	4.31
60	13.23	13.46	1.07	18.90	28.08	4.24	3.17	0.69	1.74	5.17
70	15.44	15.71	1.25	22.05	32.76	4.95	3.69	0.81	2.03	6.03
80	17.64	17.95	1.43	25.20	37.44	5.66	4.22	0.92	2.32	6.89
90	19.85	20.20	1.61	28.35	42.12	6.37	4.75	1.04	2.61	7.75
100	22.05	22.44	1.79	31.50	46.80	7.07	5.28	1.15	2.90	8.61

Table 5-9 (cont.)

PRESSURES MPa	EFFECTIVE STRESS MPa	1 PRINCIPAL STRESS MPa	2 PRINCIPAL STRESS MPa	3 PRINCIPAL STRESS MPa	MAX SHEAR STRESS MPa	VON MISES STRESS MPa
10	9.48	4.68	0.71	0.06	2.58	4.68
20	18.96	9.36	1.42	0.12	5.16	9.36
30	28.45	14.04	2.13	0.18	7.74	14.04
40	37.93	18.72	2.84	0.24	10.32	18.72
50	47.41	23.40	3.55	0.30	12.90	23.40
60	56.89	28.08	4.26	0.36	15.48	28.08
70	66.37	32.76	4.97	0.42	18.06	32.76
80	75.86	37.44	5.68	0.48	20.64	37.44
90	85.34	42.12	6.39	0.54	23.22	42.12
100	94.82	46.80	7.10	0.60	25.80	46.80

CHAPTER 6

ANALYSIS OF RESULTS

Linear and nonlinear static analysis are carried out. In nonlinear static analysis there are different types of nonlinearity (nltype) such as material, geometry and material, and geometry both mixed. Material nonlinearity analysis is carried out by defining nltype equal to material. The important feature of the software is that different load cases is defined by an EVENT ID card, which does the analysis by incremental loads. Here analysis is done for three different load cases starting with 10 MPa of pressure and having equal increments of 10 MPa each time. The final load case is 100 MPa pressure. To perform linear analysis nltype equal to linear is defined. The results of finite element analysis obtained by nonlinear static analysis at 10 MPa from the output of the software are in appendix B.

The results for the nonlinear analysis of material type are listed in Table 5-7. The analysis shows that at water jet pressure of 10 MPa, we have a shear stress of 2.584 MPa. The epidermis of skin has an ultimate strength of 10 MPa [14]. To have shear on the surface of skin, the maximum shear stress should exceed the ultimate tensile strength of layer. The shear stress is the internal total stress exerted by the material fibers along the plane to resist the action of the external forces, tending to slide the adjacent parts in opposite direction. For equilibrium conditions to exist, the shear stress at any cross section will be equal and opposite in direction to the external force. By increasing the pressure, shear stress increases and 10 MPa of maximum shear stress is achieved at about 45 MPa of water jet pressure. This means that the skin layer epidermis will have shear and will slide against 10 MPa of pressure. The second layer which is dermis will also have some shear because the ultimate strength of dermis is lower than the ultimate strength of epidermis, i.e. 5 MPa. The third layer which is subcutis does not show much effect because in the model the end nodes are fixed that is they will not have any displacement and its like much more glued to the bone.

For the analysis of the results, not only shear stress should be considered but also the displacements should be taken into account. At 10 MPa we have a maximum displacement on x-axis of 2.197 mm , on y-axis maximum displacement of 2.231 mm , z-axis maximum displacement of 0.1779 mm and maximum resultant displacement of 3.135 mm. At shearing pressure of 50 MPa, the x-axis maximum displacement is 9.586 mm, y-axis maximum displacement of 9.797 mm, the z-axis maximum displacement is 0.7792 mm and the maximum resultant displacement is 13.72 mm. This resultant displacement shows that the skin surfaces will slide 13.72 mm from its original location at 50 MPa pressure of water jet. The z-axis displacement means that the skin will be compressed, the top layer which is epidermis has the maximum compression of 0.78 mm at 50 MPa of water jet pressure.

The normal stresses are Sxx, Syy, Szz, Sxy, Syz and Szx are also listed in the Table 5-7. These stresses are the component of resultant stress which acts normal to the area considered. For special type of case consideration, these stresses should provide the stresses on the required area being considered.

In non linear analysis, the program outputs two averaged nodal effective stresses labeled as effective stress and equivalent Von-Mises stress. In principle, these stresses should be the same. However, the averaged nodal values can be different in NISA. The effective stress is calculated at integration points using components of stress tensor. This value is then projected to the nodes and averaged. The effective stress at shearing stress of 50 MPa is 42.33 MPa. The Von-Mises stress is calculated from the projected and averaged components of stress tensor. A large difference in these two nodal values indicates high stress variation in neighboring elements. The Von-Mises stress at shearing stress of 50 MPa of water jet pressure is 21 MPa.

For the purpose of analysis, it is convenient to reduce tensile, compressive, and/or shear stress to a basic system of stress coordinate known as principal stresses. These stresses act on axes which differ, in general, from the axes along which the stresses for the particular point considered. The maximum 1st principal stress at 50 MPa is 21.02 MPa, maximum 2nd principal stress at 50 MPa is 3.2 MPa and maximum 3rd principal stress at 50 MPa is 0.2325 MPa. The output results of the analysis are in appendix B.

The results obtained from the analysis shows the linear behavior because the elements are ruptured within the elastic range, that is the elements will not deform permanently. Before entering the plastic region element reaches the ultimate tensile strength. Another reason for this behavior is the layers flexibility. Gap elements are used as a gluing substance between the adjacent layers which are also responsible for this type of behavior. The gap elements used have a water property, therefore when a pressure is applied, material tends to slide before it actually shears. Also the model material is viscoelastic material. Since our main focus is the static analysis, therefore fatigue analysis was not considered, which might have shown the nonlinearity behavior of the material.

The Figure 6-1 is graph between the maximum shear stress and the water jet pressure. The Figure 6-2 is graph between the maximum resultant displacement and the water jet pressure shows the linear behavior.

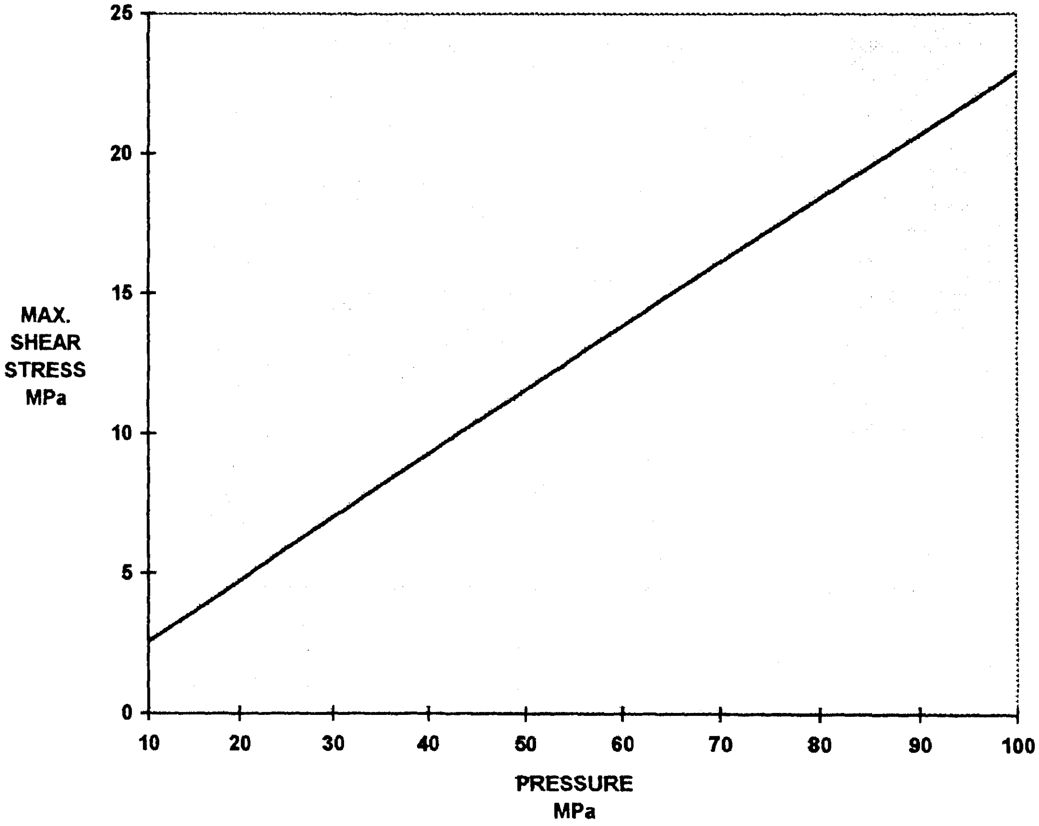


Figure 6-1 Effect of pressure on maximum shear stress from nonlinear analysis.

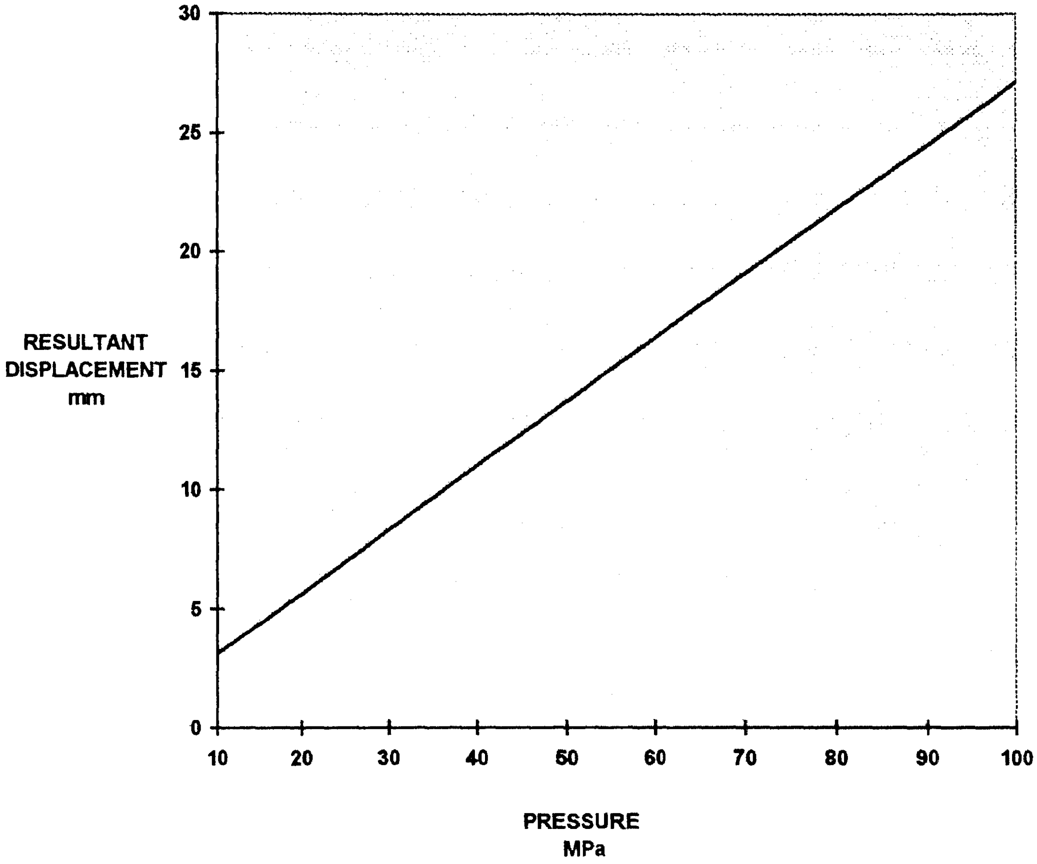


Figure 6-2 Effect of pressure on maximum resultant displacement from nonlinear analysis.

The linear static analysis is also carried out to check whether it gives the same result or not. The nonlinearity type is defined as linear and the analysis is carried out for the same load cases. The results of linear static analysis are listed in Table 5-8. The results showed the linear effect but slightly different from the nonlinearity of material type. At 10 MPa of pressure the maximum shear stress is 2.578 MPa, therefore at 40 MPa it was 10.312 MPa which is 4 times the shear stress at 10 MPa. This result is linear. The analysis does not give very different result, but in static analysis skin will have shear at approximately 40 MPa which in case of nonlinearity type of material it will be 45 MPa. All the other results like displacements and stresses were nearly same at 10 MPa from nonlinear analysis except that increasing pressure in linear analysis will have a multiple effect which is not the case in nonlinear analysis. The effect between pressure and max shear stress and effects between pressure and maximum resultant displacement are shown in Figure 6-3 & 6-4.

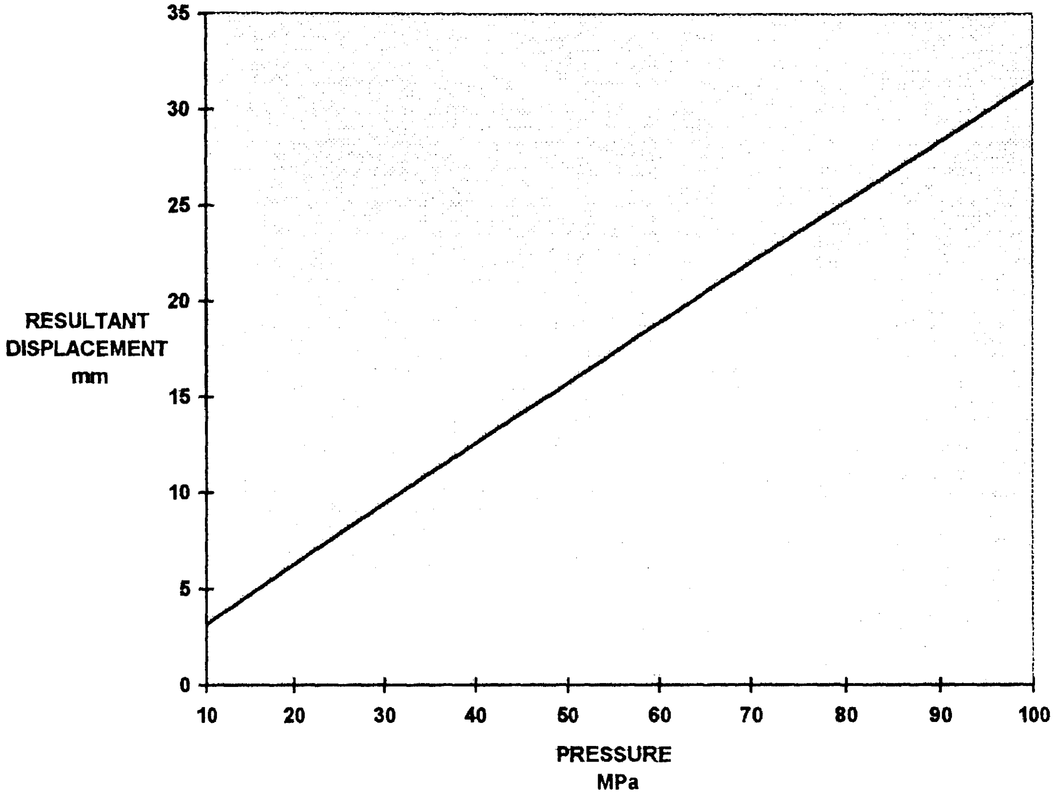


Figure 6-3 Effect of pressure on maximum resultant displacement from linear analysis.

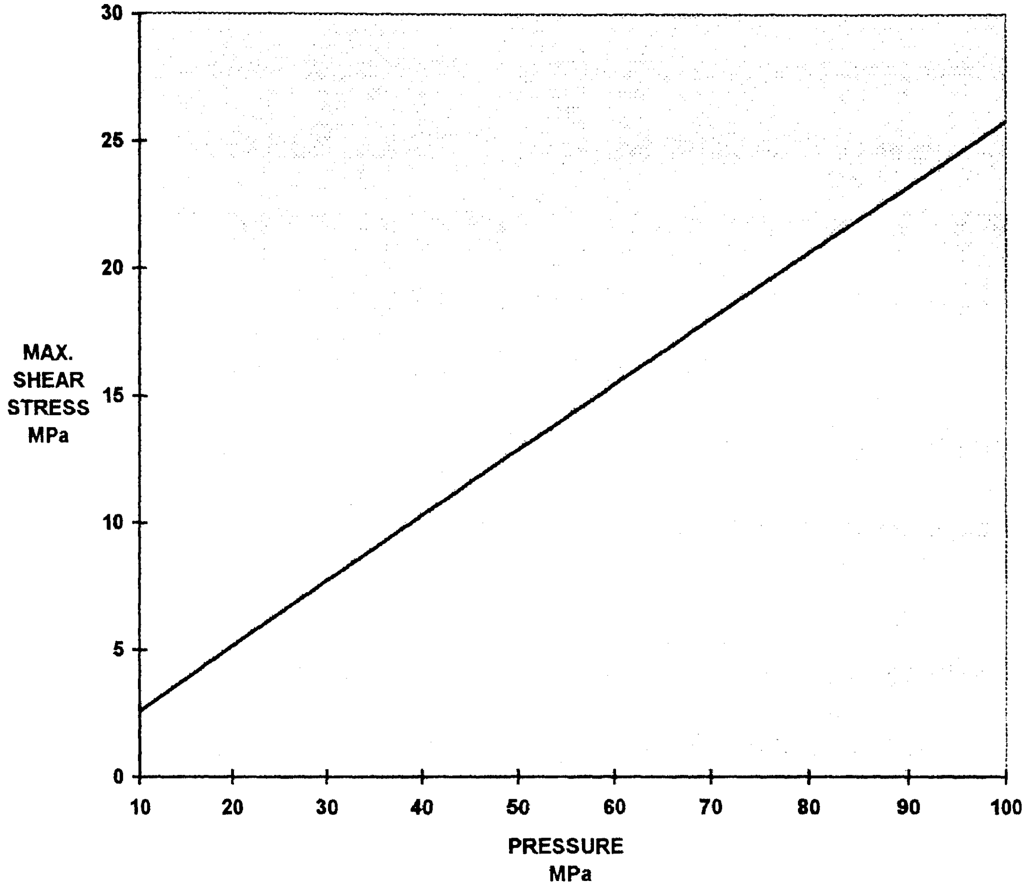


Figure 6-4 Effect of pressure on maximum shear stress from linear analysis.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The conclusions from the above analysis is that we have a working finite element model of the skin which is representative of the physical model. Linear and non linear static analyses are performed. The nonlinear static analysis shows that the skin layer will begin to shear at 45 MPa of water jet pressure and it will have the maximum resultant displacement of about 12.5 mm on the top layer epidermis. The next layer dermis will also have some displacement but the maximum displacement will be on the top layer. The skin will be compressed about 0.7 mm towards the bone. The results from this analysis are very much linear.

The linear static analysis shows that the skin layer will begin to shear at 40 MPa of water jet pressure and it will have the maximum resultant displacement of about 12.6 mm on the top layer epidermis. The skin will be compressed about 0.72 mm towards the bone. The results from this analysis are very much similar to the nonlinear type, but the change in the magnitudes are multiple i.e. increase in the pressure increases the values by the same ratio.

The results obtained from this analysis should not be used independently, they should be used to compare with the actual physical experimental results. The validity of the analysis should be checked by the surgeons who are going to use water jet for performing different types of surgery.

Further research may include the following:

1. These results are based on the data which are available and some assumptions (densities of skin components and young modulus of dermis and subcutis) for the data which are not available. In order to get a close representative model and analysis focus should be made on the collection of the data and their validity.

2. Other analysis like heat transfer and fluid mechanics should also be performed in order to get the actual characteristics of skin layer.

3. Research should be done in the area that what type of damages will be there and what are their effective treatments under condition when injury is due to pressure below shearing.

4. The higher the pressure the greater will be the cut. More research has to be done in the area that up to what pressure of water jet the bone will fracture which will provide the correct information about the condition of the patient in order to have a satisfactory treatment.

5. The effects on each layer should be studied separately in order to have a clear picture. The thickness of the skin layers i.e. epidermis, dermis and subcutis vary at different sites of the body and the increase in thickness of one constituent and decrease in thickness of another constituent will give different results. Also the number of collagen fibers which keeps the layers together may vary at different sights, therefore skin at various parts of the body behave different like skin layer on stomach have more flexibility to stretch than skin layers on hand but the skin layers on the hand have more strength. The representative skin

model here is for the skin of hand, therefore analysis should be done on the skin layers of different sites.

6. The use water jet as a surgical tool is under experiments and doctors are trying to find out whether it is safe or unsafe to have surgery with water jet. Study should be done on the side effects of the water jet, i.e. what biological effect the tissues will have after being hit by water jet.

7. One of the most important feature of water jet is that as it cuts the material it also cleans up the residuals from the shearing surface. Therefore the angle of the nozzle should be adjusted accordingly.

8. The operating parameter of water jet which is used in this analysis is pressure which is the primary parameter of water jet. But other parameters such as stand off distance, i.e. how far it is from the skin, angle of the nozzle, diameter of the nozzle, and flow rate of the water should also be considered.

APPENDIX A

NISA INPUT FILE (SKIN.NIS)

```
ANALYSIS = NLSTAT
FILE = Skin
SAVE=26,27
MAXCPU TIME = 0,0
NLTYPE = MATERIAL
*ELTYPE
 1, 14,   1
 2,  4,  20
 3, 50,   1
*RCTABLE
   1,    3,1,    0
 5.5000000E-06, 5.5000000E-06, 5.5000000E-06,
   2,    3,1,    0
 8.0000000E-06, 8.0000000E-06, 8.0000000E-06,
   3,    3,1,    0
 1.0560000E-05, 1.0560000E-05, 1.0560000E-05,
   4,    3,1,    0
 5.0000000E-03, 5.0000000E-03, 0.0000000E+00,
   5,   14,1,    0
 1.0000000E-03, 1.0000000E-03, 1.0000000E-08, 1.0000000E-08,
 0.0000000E+00, 2.5000000E-02, 0.0000000E+00, 0.0000000E+00,
 0.0000000E+00, 0.0000000E+00, 0.0000000E+00, 0.0000000E+00,
 0.0000000E+00, 1.0000000E-03,
*NODES
    1,,,,-5.00000E-01,-5.00000E-01,-2.00000E-01,    0
    2,,,,-3.00000E-01,-5.00000E-01,-2.00000E-01,    0
    3,,,,-1.00000E-01,-5.00000E-01,-2.00000E-01,    0
    4,,,, 1.00000E-01,-5.00000E-01,-2.00000E-01,    0
    5,,,, 3.00000E-01,-5.00000E-01,-2.00000E-01,    0
    6,,,, 5.00000E-01,-5.00000E-01,-2.00000E-01,    0
    7,,,,-5.00000E-01,-3.00000E-01,-2.00000E-01,    0
    8,,,,-3.00000E-01,-3.00000E-01,-2.00000E-01,    0
    9,,,,-1.00000E-01,-3.00000E-01,-2.00000E-01,    0
   10,,,, 1.00000E-01,-3.00000E-01,-2.00000E-01,    0
   11,,,, 3.00000E-01,-3.00000E-01,-2.00000E-01,    0
   12,,,, 5.00000E-01,-3.00000E-01,-2.00000E-01,    0
   13,,,,-5.00000E-01,-5.00000E-01,-1.20000E-01,    0
   14,,,,-3.00000E-01,-5.00000E-01,-1.20000E-01,    0
   15,,,,-1.00000E-01,-5.00000E-01,-1.20000E-01,    0
   16,,,, 1.00000E-01,-5.00000E-01,-1.20000E-01,    0
   17,,,, 3.00000E-01,-5.00000E-01,-1.20000E-01,    0
   18,,,, 5.00000E-01,-5.00000E-01,-1.20000E-01,    0
   19,,,,-5.00000E-01,-3.00000E-01,-1.20000E-01,    0
   20,,,,-3.00000E-01,-3.00000E-01,-1.20000E-01,    0
```

```
21,,,,-1.00000E-01,-3.00000E-01,-1.20000E-01,   0
22,,,, 1.00000E-01,-3.00000E-01,-1.20000E-01,   0
23,,,, 3.00000E-01,-3.00000E-01,-1.20000E-01,   0
24,,,, 5.00000E-01,-3.00000E-01,-1.20000E-01,   0
25,,,,-5.00000E-01,-5.00000E-01,-4.00000E-02,   0
26,,,,-3.00000E-01,-5.00000E-01,-4.00000E-02,   0
27,,,,-1.00000E-01,-5.00000E-01,-4.00000E-02,   0
28,,,, 1.00000E-01,-5.00000E-01,-4.00000E-02,   0
29,,,, 3.00000E-01,-5.00000E-01,-4.00000E-02,   0
30,,,, 5.00000E-01,-5.00000E-01,-4.00000E-02,   0
31,,,,-5.00000E-01,-3.00000E-01,-4.00000E-02,   0
32,,,,-3.00000E-01,-3.00000E-01,-4.00000E-02,   0
33,,,,-1.00000E-01,-3.00000E-01,-4.00000E-02,   0
34,,,, 1.00000E-01,-3.00000E-01,-4.00000E-02,   0
35,,,, 3.00000E-01,-3.00000E-01,-4.00000E-02,   0
36,,,, 5.00000E-01,-3.00000E-01,-4.00000E-02,   0
37,,,,-5.00000E-01,-5.00000E-01, 4.00000E-02,   0
38,,,,-3.00000E-01,-5.00000E-01, 4.00000E-02,   0
39,,,,-1.00000E-01,-5.00000E-01, 4.00000E-02,   0
40,,,, 1.00000E-01,-5.00000E-01, 4.00000E-02,   0
41,,,, 3.00000E-01,-5.00000E-01, 4.00000E-02,   0
42,,,, 5.00000E-01,-5.00000E-01, 4.00000E-02,   0
43,,,,-5.00000E-01,-3.00000E-01, 4.00000E-02,   0
44,,,,-3.00000E-01,-3.00000E-01, 4.00000E-02,   0
45,,,,-1.00000E-01,-3.00000E-01, 4.00000E-02,   0
46,,,, 1.00000E-01,-3.00000E-01, 4.00000E-02,   0
47,,,, 3.00000E-01,-3.00000E-01, 4.00000E-02,   0
48,,,, 5.00000E-01,-3.00000E-01, 4.00000E-02,   0
49,,,,-5.00000E-01,-5.00000E-01, 1.20000E-01,   0
50,,,,-3.00000E-01,-5.00000E-01, 1.20000E-01,   0
51,,,,-1.00000E-01,-5.00000E-01, 1.20000E-01,   0
52,,,, 1.00000E-01,-5.00000E-01, 1.20000E-01,   0
53,,,, 3.00000E-01,-5.00000E-01, 1.20000E-01,   0
54,,,, 5.00000E-01,-5.00000E-01, 1.20000E-01,   0
55,,,,-5.00000E-01,-3.00000E-01, 1.20000E-01,   0
56,,,,-3.00000E-01,-3.00000E-01, 1.20000E-01,   0
57,,,,-1.00000E-01,-3.00000E-01, 1.20000E-01,   0
58,,,, 1.00000E-01,-3.00000E-01, 1.20000E-01,   0
59,,,, 3.00000E-01,-3.00000E-01, 1.20000E-01,   0
60,,,, 5.00000E-01,-3.00000E-01, 1.20000E-01,   0
61,,,,-5.00000E-01,-5.00000E-01, 2.00000E-01,   0
62,,,,-3.00000E-01,-5.00000E-01, 2.00000E-01,   0
63,,,,-1.00000E-01,-5.00000E-01, 2.00000E-01,   0
64,,,, 1.00000E-01,-5.00000E-01, 2.00000E-01,   0
65,,,, 3.00000E-01,-5.00000E-01, 2.00000E-01,   0
66,,,, 5.00000E-01,-5.00000E-01, 2.00000E-01,   0
67,,,,-5.00000E-01,-3.00000E-01, 2.00000E-01,   0
68,,,,-3.00000E-01,-3.00000E-01, 2.00000E-01,   0
69,,,,-1.00000E-01,-3.00000E-01, 2.00000E-01,   0
70,,,, 1.00000E-01,-3.00000E-01, 2.00000E-01,   0
71,,,, 3.00000E-01,-3.00000E-01, 2.00000E-01,   0
72,,,, 5.00000E-01,-3.00000E-01, 2.00000E-01,   0
73,,,,-5.00000E-01,-5.00000E-01, 2.25000E-01,   0
74,,,,-4.00000E-01,-5.00000E-01, 2.25000E-01,   0
```

```
75,,,,-3.00000E-01,-5.00000E-01, 2.25000E-01,    0
76,,,,-2.00000E-01,-5.00000E-01, 2.25000E-01,    0
77,,,,-1.00000E-01,-5.00000E-01, 2.25000E-01,    0
78,,,, 0.00000E+00,-5.00000E-01, 2.25000E-01,    0
79,,,, 1.00000E-01,-5.00000E-01, 2.25000E-01,    0
80,,,, 2.00000E-01,-5.00000E-01, 2.25000E-01,    0
81,,,, 3.00000E-01,-5.00000E-01, 2.25000E-01,    0
82,,,, 4.00000E-01,-5.00000E-01, 2.25000E-01,    0
83,,,, 5.00000E-01,-5.00000E-01, 2.25000E-01,    0
84,,,,-5.00000E-01,-4.00000E-01, 2.25000E-01,    0
85,,,,-4.00000E-01,-4.00000E-01, 2.25000E-01,    0
86,,,,-3.00000E-01,-4.00000E-01, 2.25000E-01,    0
87,,,,-2.00000E-01,-4.00000E-01, 2.25000E-01,    0
88,,,,-1.00000E-01,-4.00000E-01, 2.25000E-01,    0
89,,,, 1.51788E-18,-4.00000E-01, 2.25000E-01,    0
90,,,, 1.00000E-01,-4.00000E-01, 2.25000E-01,    0
91,,,, 2.00000E-01,-4.00000E-01, 2.25000E-01,    0
92,,,, 3.00000E-01,-4.00000E-01, 2.25000E-01,    0
93,,,, 4.00000E-01,-4.00000E-01, 2.25000E-01,    0
94,,,, 5.00000E-01,-4.00000E-01, 2.25000E-01,    0
95,,,,-5.00000E-01,-3.00000E-01, 2.25000E-01,    0
96,,,,-4.00000E-01,-3.00000E-01, 2.25000E-01,    0
97,,,,-3.00000E-01,-3.00000E-01, 2.25000E-01,    0
98,,,,-2.00000E-01,-3.00000E-01, 2.25000E-01,    0
99,,,,-1.00000E-01,-3.00000E-01, 2.25000E-01,    0
100,,,, 6.72205E-18,-3.00000E-01, 2.25000E-01,    0
101,,,, 1.00000E-01,-3.00000E-01, 2.25000E-01,    0
102,,,, 2.00000E-01,-3.00000E-01, 2.25000E-01,    0
103,,,, 3.00000E-01,-3.00000E-01, 2.25000E-01,    0
104,,,, 4.00000E-01,-3.00000E-01, 2.25000E-01,    0
105,,,, 5.00000E-01,-3.00000E-01, 2.25000E-01,    0
106,,,,-5.00000E-01,-5.00000E-01, 4.25000E-01,    0
107,,,,-4.00000E-01,-5.00000E-01, 4.25000E-01,    0
108,,,,-3.00000E-01,-5.00000E-01, 4.25000E-01,    0
109,,,,-2.00000E-01,-5.00000E-01, 4.25000E-01,    0
110,,,,-1.00000E-01,-5.00000E-01, 4.25000E-01,    0
111,,,,-1.95156E-18,-5.00000E-01, 4.25000E-01,    0
112,,,, 1.00000E-01,-5.00000E-01, 4.25000E-01,    0
113,,,, 2.00000E-01,-5.00000E-01, 4.25000E-01,    0
114,,,, 3.00000E-01,-5.00000E-01, 4.25000E-01,    0
115,,,, 4.00000E-01,-5.00000E-01, 4.25000E-01,    0
116,,,, 5.00000E-01,-5.00000E-01, 4.25000E-01,    0
117,,,,-5.00000E-01,-4.00000E-01, 4.25000E-01,    0
118,,,,-4.00000E-01,-4.00000E-01, 4.25000E-01,    0
119,,,,-3.00000E-01,-4.00000E-01, 4.25000E-01,    0
120,,,,-2.00000E-01,-4.00000E-01, 4.25000E-01,    0
121,,,,-1.00000E-01,-4.00000E-01, 4.25000E-01,    0
122,,,, 1.74828E-18,-4.00000E-01, 4.25000E-01,    0
123,,,, 1.00000E-01,-4.00000E-01, 4.25000E-01,    0
124,,,, 2.00000E-01,-4.00000E-01, 4.25000E-01,    0
125,,,, 3.00000E-01,-4.00000E-01, 4.25000E-01,    0
126,,,, 4.00000E-01,-4.00000E-01, 4.25000E-01,    0
127,,,, 5.00000E-01,-4.00000E-01, 4.25000E-01,    0
128,,,,-5.00000E-01,-3.00000E-01, 4.25000E-01,    0
```

```
129,,,,-4.00000E-01,-3.00000E-01, 4.25000E-01,   0
130,,,,-3.00000E-01,-3.00000E-01, 4.25000E-01,   0
131,,,,-2.00000E-01,-3.00000E-01, 4.25000E-01,   0
132,,,,-1.00000E-01,-3.00000E-01, 4.25000E-01,   0
133,,,, 0.00000E+00,-3.00000E-01, 4.25000E-01,   0
134,,,, 1.00000E-01,-3.00000E-01, 4.25000E-01,   0
135,,,, 2.00000E-01,-3.00000E-01, 4.25000E-01,   0
136,,,, 3.00000E-01,-3.00000E-01, 4.25000E-01,   0
137,,,, 4.00000E-01,-3.00000E-01, 4.25000E-01,   0
138,,,, 5.00000E-01,-3.00000E-01, 4.25000E-01,   0
139,,,,-5.00000E-01,-5.00000E-01, 6.25000E-01,   0
140,,,,-4.00000E-01,-5.00000E-01, 6.25000E-01,   0
141,,,,-3.00000E-01,-5.00000E-01, 6.25000E-01,   0
142,,,,-2.00000E-01,-5.00000E-01, 6.25000E-01,   0
143,,,,-1.00000E-01,-5.00000E-01, 6.25000E-01,   0
144,,,, 6.72205E-18,-5.00000E-01, 6.25000E-01,   0
145,,,, 1.00000E-01,-5.00000E-01, 6.25000E-01,   0
146,,,, 2.00000E-01,-5.00000E-01, 6.25000E-01,   0
147,,,, 3.00000E-01,-5.00000E-01, 6.25000E-01,   0
148,,,, 4.00000E-01,-5.00000E-01, 6.25000E-01,   0
149,,,, 5.00000E-01,-5.00000E-01, 6.25000E-01,   0
150,,,,-5.00000E-01,-4.00000E-01, 6.25000E-01,   0
151,,,,-4.00000E-01,-4.00000E-01, 6.25000E-01,   0
152,,,,-3.00000E-01,-4.00000E-01, 6.25000E-01,   0
153,,,,-2.00000E-01,-4.00000E-01, 6.25000E-01,   0
154,,,,-1.00000E-01,-4.00000E-01, 6.25000E-01,   0
155,,,, 5.42101E-19,-4.00000E-01, 6.25000E-01,   0
156,,,, 1.00000E-01,-4.00000E-01, 6.25000E-01,   0
157,,,, 2.00000E-01,-4.00000E-01, 6.25000E-01,   0
158,,,, 3.00000E-01,-4.00000E-01, 6.25000E-01,   0
159,,,, 4.00000E-01,-4.00000E-01, 6.25000E-01,   0
160,,,, 5.00000E-01,-4.00000E-01, 6.25000E-01,   0
161,,,,-5.00000E-01,-3.00000E-01, 6.25000E-01,   0
162,,,,-4.00000E-01,-3.00000E-01, 6.25000E-01,   0
163,,,,-3.00000E-01,-3.00000E-01, 6.25000E-01,   0
164,,,,-2.00000E-01,-3.00000E-01, 6.25000E-01,   0
165,,,,-1.00000E-01,-3.00000E-01, 6.25000E-01,   0
166,,,,-3.25261E-19,-3.00000E-01, 6.25000E-01,   0
167,,,, 1.00000E-01,-3.00000E-01, 6.25000E-01,   0
168,,,, 2.00000E-01,-3.00000E-01, 6.25000E-01,   0
169,,,, 3.00000E-01,-3.00000E-01, 6.25000E-01,   0
170,,,, 4.00000E-01,-3.00000E-01, 6.25000E-01,   0
171,,,, 5.00000E-01,-3.00000E-01, 6.25000E-01,   0
172,,,,-5.00000E-01,-5.00000E-01, 8.25000E-01,   0
173,,,,-4.00000E-01,-5.00000E-01, 8.25000E-01,   0
174,,,,-3.00000E-01,-5.00000E-01, 8.25000E-01,   0
175,,,,-2.00000E-01,-5.00000E-01, 8.25000E-01,   0
176,,,,-1.00000E-01,-5.00000E-01, 8.25000E-01,   0
177,,,,-6.93889E-18,-5.00000E-01, 8.25000E-01,   0
178,,,, 1.00000E-01,-5.00000E-01, 8.25000E-01,   0
179,,,, 2.00000E-01,-5.00000E-01, 8.25000E-01,   0
180,,,, 3.00000E-01,-5.00000E-01, 8.25000E-01,   0
181,,,, 4.00000E-01,-5.00000E-01, 8.25000E-01,   0
182,,,, 5.00000E-01,-5.00000E-01, 8.25000E-01,   0
```

```
183,,,,-5.00000E-01,-4.00000E-01, 8.25000E-01,   0
184,,,,-4.00000E-01,-4.00000E-01, 8.25000E-01,   0
185,,,,-3.00000E-01,-4.00000E-01, 8.25000E-01,   0
186,,,,-2.00000E-01,-4.00000E-01, 8.25000E-01,   0
187,,,,-1.00000E-01,-4.00000E-01, 8.25000E-01,   0
188,,,,-4.74338E-20,-4.00000E-01, 8.25000E-01,   0
189,,,, 1.00000E-01,-4.00000E-01, 8.25000E-01,   0
190,,,, 2.00000E-01,-4.00000E-01, 8.25000E-01,   0
191,,,, 3.00000E-01,-4.00000E-01, 8.25000E-01,   0
192,,,, 4.00000E-01,-4.00000E-01, 8.25000E-01,   0
193,,,, 5.00000E-01,-4.00000E-01, 8.25000E-01,   0
194,,,,-5.00000E-01,-3.00000E-01, 8.25000E-01,   0
195,,,,-4.00000E-01,-3.00000E-01, 8.25000E-01,   0
196,,,,-3.00000E-01,-3.00000E-01, 8.25000E-01,   0
197,,,,-2.00000E-01,-3.00000E-01, 8.25000E-01,   0
198,,,,-1.00000E-01,-3.00000E-01, 8.25000E-01,   0
199,,,, 1.41285E-18,-3.00000E-01, 8.25000E-01,   0
200,,,, 1.00000E-01,-3.00000E-01, 8.25000E-01,   0
201,,,, 2.00000E-01,-3.00000E-01, 8.25000E-01,   0
202,,,, 3.00000E-01,-3.00000E-01, 8.25000E-01,   0
203,,,, 4.00000E-01,-3.00000E-01, 8.25000E-01,   0
204,,,, 5.00000E-01,-3.00000E-01, 8.25000E-01,   0
205,,,,-5.00000E-01,-5.00000E-01, 1.02500E+00,   0
206,,,,-4.00000E-01,-5.00000E-01, 1.02500E+00,   0
207,,,,-3.00000E-01,-5.00000E-01, 1.02500E+00,   0
208,,,,-2.00000E-01,-5.00000E-01, 1.02500E+00,   0
209,,,,-1.00000E-01,-5.00000E-01, 1.02500E+00,   0
210,,,, 2.38524E-18,-5.00000E-01, 1.02500E+00,   0
211,,,, 1.00000E-01,-5.00000E-01, 1.02500E+00,   0
212,,,, 2.00000E-01,-5.00000E-01, 1.02500E+00,   0
213,,,, 3.00000E-01,-5.00000E-01, 1.02500E+00,   0
214,,,, 4.00000E-01,-5.00000E-01, 1.02500E+00,   0
215,,,, 5.00000E-01,-5.00000E-01, 1.02500E+00,   0
216,,,,-5.00000E-01,-4.00000E-01, 1.02500E+00,   0
217,,,,-4.00000E-01,-4.00000E-01, 1.02500E+00,   0
218,,,,-3.00000E-01,-4.00000E-01, 1.02500E+00,   0
219,,,,-2.00000E-01,-4.00000E-01, 1.02500E+00,   0
220,,,,-1.00000E-01,-4.00000E-01, 1.02500E+00,   0
221,,,,-9.82558E-19,-4.00000E-01, 1.02500E+00,   0
222,,,, 1.00000E-01,-4.00000E-01, 1.02500E+00,   0
223,,,, 2.00000E-01,-4.00000E-01, 1.02500E+00,   0
224,,,, 3.00000E-01,-4.00000E-01, 1.02500E+00,   0
225,,,, 4.00000E-01,-4.00000E-01, 1.02500E+00,   0
226,,,, 5.00000E-01,-4.00000E-01, 1.02500E+00,   0
227,,,,-5.00000E-01,-3.00000E-01, 1.02500E+00,   0
228,,,,-4.00000E-01,-3.00000E-01, 1.02500E+00,   0
229,,,,-3.00000E-01,-3.00000E-01, 1.02500E+00,   0
230,,,,-2.00000E-01,-3.00000E-01, 1.02500E+00,   0
231,,,,-1.00000E-01,-3.00000E-01, 1.02500E+00,   0
232,,,,-3.90313E-18,-3.00000E-01, 1.02500E+00,   0
233,,,, 1.00000E-01,-3.00000E-01, 1.02500E+00,   0
234,,,, 2.00000E-01,-3.00000E-01, 1.02500E+00,   0
235,,,, 3.00000E-01,-3.00000E-01, 1.02500E+00,   0
236,,,, 4.00000E-01,-3.00000E-01, 1.02500E+00,   0
```

```
237,,,, 5.00000E-01,-3.00000E-01, 1.02500E+00,    0
238,,,,-5.00000E-01,-5.00000E-01, 1.22500E+00,    0
239,,,,-4.00000E-01,-5.00000E-01, 1.22500E+00,    0
240,,,,-3.00000E-01,-5.00000E-01, 1.22500E+00,    0
241,,,,-2.00000E-01,-5.00000E-01, 1.22500E+00,    0
242,,,,-1.00000E-01,-5.00000E-01, 1.22500E+00,    0
243,,,, 0.00000E+00,-5.00000E-01, 1.22500E+00,     0
244,,,, 1.00000E-01,-5.00000E-01, 1.22500E+00,    0
245,,,, 2.00000E-01,-5.00000E-01, 1.22500E+00,    0
246,,,, 3.00000E-01,-5.00000E-01, 1.22500E+00,    0
247,,,, 4.00000E-01,-5.00000E-01, 1.22500E+00,    0
248,,,, 5.00000E-01,-5.00000E-01, 1.22500E+00,    0
249,,,,-5.00000E-01,-4.00000E-01, 1.22500E+00,    0
250,,,,-4.00000E-01,-4.00000E-01, 1.22500E+00,    0
251,,,,-3.00000E-01,-4.00000E-01, 1.22500E+00,    0
252,,,,-2.00000E-01,-4.00000E-01, 1.22500E+00,    0
253,,,,-1.00000E-01,-4.00000E-01, 1.22500E+00,    0
254,,,,-1.82959E-18,-4.00000E-01, 1.22500E+00,    0
255,,,, 1.00000E-01,-4.00000E-01, 1.22500E+00,    0
256,,,, 2.00000E-01,-4.00000E-01, 1.22500E+00,    0
257,,,, 3.00000E-01,-4.00000E-01, 1.22500E+00,    0
258,,,, 4.00000E-01,-4.00000E-01, 1.22500E+00,    0
259,,,, 5.00000E-01,-4.00000E-01, 1.22500E+00,    0
260,,,,-5.00000E-01,-3.00000E-01, 1.22500E+00,    0
261,,,,-4.00000E-01,-3.00000E-01, 1.22500E+00,    0
262,,,,-3.00000E-01,-3.00000E-01, 1.22500E+00,    0
263,,,,-2.00000E-01,-3.00000E-01, 1.22500E+00,    0
264,,,,-1.00000E-01,-3.00000E-01, 1.22500E+00,    0
265,,,,-4.20128E-19,-3.00000E-01, 1.22500E+00,    0
266,,,, 1.00000E-01,-3.00000E-01, 1.22500E+00,    0
267,,,, 2.00000E-01,-3.00000E-01, 1.22500E+00,    0
268,,,, 3.00000E-01,-3.00000E-01, 1.22500E+00,    0
269,,,, 4.00000E-01,-3.00000E-01, 1.22500E+00,    0
270,,,, 5.00000E-01,-3.00000E-01, 1.22500E+00,    0
271,,,,-5.00000E-01,-5.00000E-01, 1.42500E+00,    0
272,,,,-4.00000E-01,-5.00000E-01, 1.42500E+00,    0
273,,,,-3.00000E-01,-5.00000E-01, 1.42500E+00,    0
274,,,,-2.00000E-01,-5.00000E-01, 1.42500E+00,    0
275,,,,-1.00000E-01,-5.00000E-01, 1.42500E+00,    0
276,,,, 0.00000E+00,-5.00000E-01, 1.42500E+00,     0
277,,,, 1.00000E-01,-5.00000E-01, 1.42500E+00,    0
278,,,, 2.00000E-01,-5.00000E-01, 1.42500E+00,    0
279,,,, 3.00000E-01,-5.00000E-01, 1.42500E+00,    0
280,,,, 4.00000E-01,-5.00000E-01, 1.42500E+00,    0
281,,,, 5.00000E-01,-5.00000E-01, 1.42500E+00,    0
282,,,,-5.00000E-01,-4.00000E-01, 1.42500E+00,    0
283,,,,-4.00000E-01,-4.00000E-01, 1.42500E+00,    0
284,,,,-3.00000E-01,-4.00000E-01, 1.42500E+00,    0
285,,,,-2.00000E-01,-4.00000E-01, 1.42500E+00,    0
286,,,,-1.00000E-01,-4.00000E-01, 1.42500E+00,    0
287,,,, 1.02999E-18,-4.00000E-01, 1.42500E+00,    0
288,,,, 1.00000E-01,-4.00000E-01, 1.42500E+00,    0
289,,,, 2.00000E-01,-4.00000E-01, 1.42500E+00,    0
290,,,, 3.00000E-01,-4.00000E-01, 1.42500E+00,    0
```

```
291,,,, 4.00000E-01,-4.00000E-01, 1.42500E+00,    0
292,,,, 5.00000E-01,-4.00000E-01, 1.42500E+00,    0
293,,,,-5.00000E-01,-3.00000E-01, 1.42500E+00,    0
294,,,,-4.00000E-01,-3.00000E-01, 1.42500E+00,    0
295,,,,-3.00000E-01,-3.00000E-01, 1.42500E+00,    0
296,,,,-2.00000E-01,-3.00000E-01, 1.42500E+00,    0
297,,,,-1.00000E-01,-3.00000E-01, 1.42500E+00,    0
298,,,, 3.68629E-18,-3.00000E-01, 1.42500E+00,    0
299,,,, 1.00000E-01,-3.00000E-01, 1.42500E+00,    0
300,,,, 2.00000E-01,-3.00000E-01, 1.42500E+00,    0
301,,,, 3.00000E-01,-3.00000E-01, 1.42500E+00,    0
302,,,, 4.00000E-01,-3.00000E-01, 1.42500E+00,    0
303,,,, 5.00000E-01,-3.00000E-01, 1.42500E+00,    0
304,,,,-5.00000E-01,-5.00000E-01, 1.62500E+00,    0
305,,,,-4.00000E-01,-5.00000E-01, 1.62500E+00,    0
306,,,,-3.00000E-01,-5.00000E-01, 1.62500E+00,    0
307,,,,-2.00000E-01,-5.00000E-01, 1.62500E+00,    0
308,,,,-1.00000E-01,-5.00000E-01, 1.62500E+00,    0
309,,,,-6.93889E-18,-5.00000E-01, 1.62500E+00,    0
310,,,, 1.00000E-01,-5.00000E-01, 1.62500E+00,    0
311,,,, 2.00000E-01,-5.00000E-01, 1.62500E+00,    0
312,,,, 3.00000E-01,-5.00000E-01, 1.62500E+00,    0
313,,,, 4.00000E-01,-5.00000E-01, 1.62500E+00,    0
314,,,, 5.00000E-01,-5.00000E-01, 1.62500E+00,    0
315,,,,-5.00000E-01,-4.00000E-01, 1.62500E+00,    0
316,,,,-4.00000E-01,-4.00000E-01, 1.62500E+00,    0
317,,,,-3.00000E-01,-4.00000E-01, 1.62500E+00.    0
318,,,,-2.00000E-01,-4.00000E-01, 1.62500E+00,    0
319,,,,-1.00000E-01,-4.00000E-01, 1.62500E+00,    0
320,,,,-5.19062E-18,-4.00000E-01, 1.62500E+00,    0
321,,,, 1.00000E-01,-4.00000E-01, 1.62500E+00,    0
322,,,, 2.00000E-01,-4.00000E-01, 1.62500E+00,    0
323,,,, 3.00000E-01,-4.00000E-01, 1.62500E+00,    0
324,,,, 4.00000E-01,-4.00000E-01, 1.62500E+00,    0
325,,,, 5.00000E-01,-4.00000E-01, 1.62500E+00,    0
326,,,,-5.00000E-01,-3.00000E-01, 1.62500E+00,    0
327,,,,-4.00000E-01,-3.00000E-01, 1.62500E+00,    0
328,,,,-3.00000E-01,-3.00000E-01, 1.62500E+00,    0
329,,,,-2.00000E-01,-3.00000E-01, 1.62500E+00,    0
330,,,,-1.00000E-01,-3.00000E-01, 1.62500E+00,    0
331,,,, 8.63296E-18,-3.00000E-01, 1.62500E+00,    0
332,,,, 1.00000E-01,-3.00000E-01, 1.62500E+00,    0
333,,,, 2.00000E-01,-3.00000E-01, 1.62500E+00,    0
334,,,, 3.00000E-01,-3.00000E-01, 1.62500E+00,    0
335,,,, 4.00000E-01,-3.00000E-01, 1.62500E+00,    0
336,,,, 5.00000E-01,-3.00000E-01, 1.62500E+00,    0
337,,,,-5.00000E-01,-5.00000E-01, 1.82500E+00,    0
338,,,,-4.00000E-01,-5.00000E-01, 1.82500E+00,    0
339,,,,-3.00000E-01,-5.00000E-01, 1.82500E+00,    0
340,,,,-2.00000E-01,-5.00000E-01, 1.82500E+00,    0
341,,,,-1.00000E-01,-5.00000E-01, 1.82500E+00,    0
342,,,, 8.67362E-19,-5.00000E-01, 1.82500E+00,    0
343,,,, 1.00000E-01,-5.00000E-01, 1.82500E+00,    0
344,,,, 2.00000E-01,-5.00000E-01, 1.82500E+00,    0
```

```
345,,,, 3.00000E-01,-5.00000E-01, 1.82500E+00,   0
346,,,, 4.00000E-01,-5.00000E-01, 1.82500E+00,   0
347,,,, 5.00000E-01,-5.00000E-01, 1.82500E+00,   0
348,,,,-5.00000E-01,-4.00000E-01, 1.82500E+00,   0
349,,,,-4.00000E-01,-4.00000E-01, 1.82500E+00,   0
350,,,,-3.00000E-01,-4.00000E-01, 1.82500E+00,   0
351,,,,-2.00000E-01,-4.00000E-01, 1.82500E+00,   0
352,,,,-1.00000E-01,-4.00000E-01, 1.82500E+00,   0
353,,,, 3.52366E-18,-4.00000E-01, 1.82500E+00,   0
354,,,, 1.00000E-01,-4.00000E-01, 1.82500E+00,   0
355,,,, 2.00000E-01,-4.00000E-01, 1.82500E+00,   0
356,,,, 3.00000E-01,-4.00000E-01, 1.82500E+00,   0
357,,,, 4.00000E-01,-4.00000E-01, 1.82500E+00,   0
358,,,, 5.00000E-01,-4.00000E-01, 1.82500E+00,   0
359,,,,-5.00000E-01,-3.00000E-01, 1.82500E+00,   0
360,,,,-4.00000E-01,-3.00000E-01, 1.82500E+00,   0
361,,,,-3.00000E-01,-3.00000E-01, 1.82500E+00,   0
362,,,,-2.00000E-01,-3.00000E-01, 1.82500E+00,   0
363,,,,-1.00000E-01,-3.00000E-01, 1.82500E+00,   0
364,,,,-7.75205E-18,-3.00000E-01, 1.82500E+00,   0
365,,,, 1.00000E-01,-3.00000E-01, 1.82500E+00,   0
366,,,, 2.00000E-01,-3.00000E-01, 1.82500E+00,   0
367,,,, 3.00000E-01,-3.00000E-01, 1.82500E+00,   0
368,,,, 4.00000E-01,-3.00000E-01, 1.82500E+00,   0
369,,,, 5.00000E-01,-3.00000E-01, 1.82500E+00,   0
370,,,,-5.00000E-01,-5.00000E-01, 2.02500E+00,   0
371,,,,-4.00000E-01,-5.00000E-01, 2.02500E+00,   0
372,,,,-3.00000E-01,-5.00000E-01, 2.02500E+00,   0
373,,,,-2.00000E-01,-5.00000E-01, 2.02500E+00,   0
374,,,,-1.00000E-01,-5.00000E-01, 2.02500E+00,   0
375,,,, 0.00000E+00,-5.00000E-01, 2.02500E+00,   0
376,,,, 1.00000E-01,-5.00000E-01, 2.02500E+00,   0
377,,,, 2.00000E-01,-5.00000E-01, 2.02500E+00,   0
378,,,, 3.00000E-01,-5.00000E-01, 2.02500E+00,   0
379,,,, 4.00000E-01,-5.00000E-01, 2.02500E+00,   0
380,,,, 5.00000E-01,-5.00000E-01, 2.02500E+00,   0
381,,,,-5.00000E-01,-4.00000E-01, 2.02500E+00,   0
382,,,,-4.00000E-01,-4.00000E-01, 2.02500E+00,   0
383,,,,-3.00000E-01,-4.00000E-01, 2.02500E+00,   0
384,,,,-2.00000E-01,-4.00000E-01, 2.02500E+00,   0
385,,,,-1.00000E-01,-4.00000E-01, 2.02500E+00,   0
386,,,, 4.33681E-18,-4.00000E-01, 2.02500E+00,   0
387,,,, 1.00000E-01,-4.00000E-01, 2.02500E+00,   0
388,,,, 2.00000E-01,-4.00000E-01, 2.02500E+00,   0
389,,,, 3.00000E-01,-4.00000E-01, 2.02500E+00,   0
390,,,, 4.00000E-01,-4.00000E-01, 2.02500E+00,   0
391,,,, 5.00000E-01,-4.00000E-01, 2.02500E+00,   0
392,,,,-5.00000E-01,-3.00000E-01, 2.02500E+00,   0
393,,,,-4.00000E-01,-3.00000E-01, 2.02500E+00,   0
394,,,,-3.00000E-01,-3.00000E-01, 2.02500E+00,   0
395,,,,-2.00000E-01,-3.00000E-01, 2.02500E+00,   0
396,,,,-1.00000E-01,-3.00000E-01, 2.02500E+00,   0
397,,,,-1.08420E-19,-3.00000E-01, 2.02500E+00,   0
398,,,, 1.00000E-01,-3.00000E-01, 2.02500E+00,   0
```

```
399,,,, 2.00000E-01,-3.00000E-01, 2.02500E+00,    0
400,,,, 3.00000E-01,-3.00000E-01, 2.02500E+00,    0
401,,,, 4.00000E-01,-3.00000E-01, 2.02500E+00,    0
402,,,, 5.00000E-01,-3.00000E-01, 2.02500E+00,    0
403,,,,-5.00000E-01,-5.00000E-01, 2.22500E+00,    0
404,,,,-4.00000E-01,-5.00000E-01, 2.22500E+00,    0
405,,,,-3.00000E-01,-5.00000E-01, 2.22500E+00,    0
406,,,,-2.00000E-01,-5.00000E-01, 2.22500E+00,    0
407,,,,-1.00000E-01,-5.00000E-01, 2.22500E+00,    0
408,,,, 0.00000E+00,-5.00000E-01, 2.22500E+00,    0
409,,,, 1.00000E-01,-5.00000E-01, 2.22500E+00,    0
410,,,, 2.00000E-01,-5.00000E-01, 2.22500E+00,    0
411,,,, 3.00000E-01,-5.00000E-01, 2.22500E+00,    0
412,,,, 4.00000E-01,-5.00000E-01, 2.22500E+00,    0
413,,,, 5.00000E-01,-5.00000E-01, 2.22500E+00,    0
414,,,,-5.00000E-01,-4.00000E-01, 2.22500E+00,    0
415,,,,-4.00000E-01,-4.00000E-01, 2.22500E+00,    0
416,,,,-3.00000E-01,-4.00000E-01, 2.22500E+00,    0
417,,,,-2.00000E-01,-4.00000E-01, 2.22500E+00,    0
418,,,,-1.00000E-01,-4.00000E-01, 2.22500E+00,    0
419,,,, 1.51788E-18,-4.00000E-01, 2.22500E+00,    0
420,,,, 1.00000E-01,-4.00000E-01, 2.22500E+00,    0
421,,,, 2.00000E-01,-4.00000E-01, 2.22500E+00,    0
422,,,, 3.00000E-01,-4.00000E-01, 2.22500E+00,    0
423,,,, 4.00000E-01,-4.00000E-01, 2.22500E+00,    0
424,,,, 5.00000E-01,-4.00000E-01, 2.22500E+00,    0
425,,,,-5.00000E-01,-3.00000E-01, 2.22500E+00,    0
426,,,,-4.00000E-01,-3.00000E-01, 2.22500E+00,    0
427,,,,-3.00000E-01,-3.00000E-01, 2.22500E+00,    0
428,,,,-2.00000E-01,-3.00000E-01, 2.22500E+00,    0
429,,,,-1.00000E-01,-3.00000E-01, 2.22500E+00,    0
430,,,, 6.72205E-18,-3.00000E-01, 2.22500E+00,    0
431,,,, 1.00000E-01,-3.00000E-01, 2.22500E+00,    0
432,,,, 2.00000E-01,-3.00000E-01, 2.22500E+00,    0
433,,,, 3.00000E-01,-3.00000E-01, 2.22500E+00,    0
434,,,, 4.00000E-01,-3.00000E-01, 2.22500E+00,    0
435,,,, 5.00000E-01,-3.00000E-01, 2.22500E+00,    0
436,,,,-5.00000E-01,-5.00000E-01, 2.24500E+00,    0
437,,,,-3.00000E-01,-5.00000E-01, 2.24500E+00,    0
438,,,,-1.00000E-01,-5.00000E-01, 2.24500E+00,    0
439,,,, 1.00000E-01,-5.00000E-01, 2.24500E+00,    0
440,,,, 3.00000E-01,-5.00000E-01, 2.24500E+00,    0
441,,,, 5.00000E-01,-5.00000E-01, 2.24500E+00,    0
442,,,,-5.00000E-01,-3.00000E-01, 2.24500E+00,    0
443,,,,-3.00000E-01,-3.00000E-01, 2.24500E+00,    0
444,,,,-1.00000E-01,-3.00000E-01, 2.24500E+00,    0
445,,,, 1.00000E-01,-3.00000E-01, 2.24500E+00,    0
446,,,, 3.00000E-01,-3.00000E-01, 2.24500E+00,    0
447,,,, 5.00000E-01,-3.00000E-01, 2.24500E+00,    0
448,,,,-5.00000E-01,-5.00000E-01, 2.26500E+00,    0
449,,,,-3.00000E-01,-5.00000E-01, 2.26500E+00,    0
450,,,,-1.00000E-01,-5.00000E-01, 2.26500E+00,    0
451,,,, 1.00000E-01,-5.00000E-01, 2.26500E+00,    0
452,,,, 3.00000E-01,-5.00000E-01, 2.26500E+00,    0
```

```
453,,,, 5.00000E-01,-5.00000E-01, 2.26500E+00,    0
454,,,,-5.00000E-01,-3.00000E-01, 2.26500E+00,    0
455,,,,-3.00000E-01,-3.00000E-01, 2.26500E+00,    0
456,,,,-1.00000E-01,-3.00000E-01, 2.26500E+00,    0
457,,,, 1.00000E-01,-3.00000E-01, 2.26500E+00,    0
458,,,, 3.00000E-01,-3.00000E-01, 2.26500E+00,    0
459,,,, 5.00000E-01,-3.00000E-01, 2.26500E+00,    0
460,,,,-5.00000E-01,-5.00000E-01, 2.28500E+00,    0
461,,,,-3.00000E-01,-5.00000E-01, 2.28500E+00,    0
462,,,,-1.00000E-01,-5.00000E-01, 2.28500E+00,    0
463,,,, 1.00000E-01,-5.00000E-01, 2.28500E+00,    0
464,,,, 3.00000E-01,-5.00000E-01, 2.28500E+00,    0
465,,,, 5.00000E-01,-5.00000E-01, 2.28500E+00,    0
466,,,,-5.00000E-01,-3.00000E-01, 2.28500E+00,    0
467,,,,-3.00000E-01,-3.00000E-01, 2.28500E+00,    0
468,,,,-1.00000E-01,-3.00000E-01, 2.28500E+00,    0
469,,,, 1.00000E-01,-3.00000E-01, 2.28500E+00,    0
470,,,, 3.00000E-01,-3.00000E-01, 2.28500E+00,    0
471,,,, 5.00000E-01,-3.00000E-01, 2.28500E+00,    0
472,,,,-5.00000E-01,-5.00000E-01, 2.30500E+00,    0
473,,,,-3.00000E-01,-5.00000E-01, 2.30500E+00,    0
474,,,,-1.00000E-01,-5.00000E-01, 2.30500E+00,    0
475,,,, 1.00000E-01,-5.00000E-01, 2.30500E+00,    0
476,,,, 3.00000E-01,-5.00000E-01, 2.30500E+00,    0
477,,,, 5.00000E-01,-5.00000E-01, 2.30500E+00,    0
478,,,,-5.00000E-01,-3.00000E-01, 2.30500E+00,    0
479,,,,-3.00000E-01,-3.00000E-01, 2.30500E+00,    0
480,,,,-1.00000E-01,-3.00000E-01, 2.30500E+00,    0
481,,,, 1.00000E-01,-3.00000E-01, 2.30500E+00,    0
482,,,, 3.00000E-01,-3.00000E-01, 2.30500E+00,    0
483,,,, 5.00000E-01,-3.00000E-01, 2.30500E+00,    0
484,,,,-5.00000E-01,-5.00000E-01, 2.32500E+00,    0
485,,,,-3.00000E-01,-5.00000E-01, 2.32500E+00,    0
486,,,,-1.00000E-01,-5.00000E-01, 2.32500E+00,    0
487,,,, 1.00000E-01,-5.00000E-01, 2.32500E+00,    0
488,,,, 3.00000E-01,-5.00000E-01, 2.32500E+00,    0
489,,,, 5.00000E-01,-5.00000E-01, 2.32500E+00,    0
490,,,,-5.00000E-01,-3.00000E-01, 2.32500E+00,    0
491,,,,-3.00000E-01,-3.00000E-01, 2.32500E+00,    0
492,,,,-1.00000E-01,-3.00000E-01, 2.32500E+00,    0
493,,,, 1.00000E-01,-3.00000E-01, 2.32500E+00,    0
494,,,, 3.00000E-01,-3.00000E-01, 2.32500E+00,    0
495,,,, 5.00000E-01,-3.00000E-01, 2.32500E+00,    0
496,,,,-5.00000E-01,-5.00000E-01, 2.34500E+00,    0
497,,,,-3.00000E-01,-5.00000E-01, 2.34500E+00,    0
498,,,,-1.00000E-01,-5.00000E-01, 2.34500E+00,    0
499,,,, 1.00000E-01,-5.00000E-01, 2.34500E+00,    0
500,,,, 3.00000E-01,-5.00000E-01, 2.34500E+00,    0
501,,,, 5.00000E-01,-5.00000E-01, 2.34500E+00,    0
502,,,,-5.00000E-01,-3.00000E-01, 2.34500E+00,    0
503,,,,-3.00000E-01,-3.00000E-01, 2.34500E+00,    0
504,,,,-1.00000E-01,-3.00000E-01, 2.34500E+00,    0
505,,,, 1.00000E-01,-3.00000E-01, 2.34500E+00,    0
506,,,, 3.00000E-01,-3.00000E-01, 2.34500E+00,    0
```

```
  507,,,, 5.00000E-01,-3.00000E-01, 2.34500E+00,     0
*ELEMENTS
 1294,    1,    2,    1,    0
   1,    8,    7,   19,
 1295,    1,    2,    1,    0
   1,    2,    8,   14,
 1296,    1,    2,    1,    0
   8,    2,    3,   14,
 1297,    1,    2,    1,    0
   8,    3,    9,   21,
 1298,    1,    2,    1,    0
   3,   10,    9,   21,
 1299,    1,    2,    1,    0
   3,    4,   10,   16,
 1300,    1,    2,    1,    0
  10,    4,    5,   16,
 1301,    1,    2,    1,    0
  10,    5,   11,   23,
 1302,    1,    2,    1,    0
   5,   12,   11,   23,
 1303,    1,    2,    1,    0
   5,    6,   12,   18,
 1304,    1,    2,    1,    0
   1,    8,   19,   14,
 1305,    1,    2,    1,    0
   8,   14,    3,   21,
 1306,    1,    2,    1,    0
   3,   10,   21,   16,
 1307,    1,    2,    1,    0
  10,   16,    5,   23,
 1308,    1,    2,    1,    0
   5,   12,   23,   18,
 1309,    1,    2,    1,    0
   1,   13,   14,   19,
 1310,    1,    2,    1,    0
   8,   19,   14,   20,
 1311,    1,    2,    1,    0
   8,   20,   14,   21,
 1312,    1,    2,    1,    0
  14,   15,    3,   21,
 1313,    1,    2,    1,    0
   3,   15,   16,   21,
 1314,    1,    2,    1,    0
  10,   21,   16,   22,
 1315,    1,    2,    1,    0
  10,   22,   16,   23,
 1316,    1,    2,    1,    0
  16,   17,    5,   23,
 1317,    1,    2,    1,    0
   5,   17,   18,   23,
 1318,    1,    2,    1,    0
  12,   23,   18,   24,
 1319,    1,    2,    1,    0
  19,   13,   14,   25,
```

```
1320,   1,   2,   1,   0
  19,  14,  20,  32,
1321,   1,   2,   1,   0
  14,  21,  20,  32,
1322,   1,   2,   1,   0
  14,  15,  21,  27,
1323,   1,   2,   1,   0
  21,  15,  16,  27,
1324,   1,   2,   1,   0
  21,  16,  22,  34,
1325,   1,   2,   1,   0
  16,  23,  22,  34,
1326,   1,   2,   1,   0
  16,  17,  23,  29,
1327,   1,   2,   1,   0
  23,  17,  18,  29,
1328,   1,   2,   1,   0
  23,  18,  24,  36,
1329,   1,   2,   1,   0
  19,  25,  14,  32,
1330,   1,   2,   1,   0
  14,  21,  32,  27,
1331,   1,   2,   1,   0
  21,  27,  16,  34,
1332,   1,   2,   1,   0
  16,  23,  34,  29,
1333,   1,   2,   1,   0
  23,  29,  18,  36,
1334,   1,   2,   1,   0
  19,  31,  25,  32,
1335,   1,   2,   1,   0
  25,  26,  14,  32,
1336,   1,   2,   1,   0
  14,  26,  27,  32,
1337,   1,   2,   1,   0
  21,  32,  27,  33,
1338,   1,   2,   1,   0
  21,  33,  27,  34,
1339,   1,   2,   1,   0
  27,  28,  16,  34,
1340,   1,   2,   1,   0
  16,  28,  29,  34,
1341,   1,   2,   1,   0
  23,  34,  29,  35,
1342,   1,   2,   1,   0
  23,  35,  29,  36,
1343,   1,   2,   1,   0
  29,  30,  18,  36,
1344,   1,   2,   1,   0
  25,  32,  31,  43,
1345,   1,   2,   1,   0
  25,  26,  32,  38,
1346,   1,   2,   1,   0
  32,  26,  27,  38,
```

```
1347,   1,   2,   1,   0
  32,  27,  33,  45,
1348,   1,   2,   1,   0
  27,  34,  33,  45,
1349,   1,   2,   1,   0
  27,  28,  34,  40,
1350,   1,   2,   1,   0
  34,  28,  29,  40,
1351,   1,   2,   1,   0
  34,  29,  35,  47,
1352,   1,   2,   1,   0
  29,  36,  35,  47,
1353,   1,   2,   1,   0
  29,  30,  36,  42,
1354,   1,   2,   1,   0
  25,  32,  43,  38,
1355,   1,   2,   1,   0
  32,  38,  27,  45,
1356,   1,   2,   1,   0
  27,  34,  45,  40,
1357,   1,   2,   1,   0
  34,  40,  29,  47,
1358,   1,   2,   1,   0
  29,  36,  47,  42,
1359,   1,   2,   1,   0
  25,  37,  38,  43,
1360,   1,   2,   1,   0
  32,  43,  38,  44,
1361,   1,   2,   1,   0
  32,  44,  38,  45,
1362,   1,   2,   1,   0
  38,  39,  27,  45,
1363,   1,   2,   1,   0
  27,  39,  40,  45,
1364,   1,   2,   1,   0
  34,  45,  40,  46,
1365,   1,   2,   1,   0
  34,  46,  40,  47,
1366,   1,   2,   1,   0
  40,  41,  29,  47,
1367,   1,   2,   1,   0
  29,  41,  42,  47,
1368,   1,   2,   1,   0
  36,  47,  42,  48,
1369,   1,   2,   1,   0
  43,  37,  38,  49,
1370,   1,   2,   1,   0
  43,  38,  44,  56,
1371,   1,   2,   1,   0
  38,  45,  44,  56,
1372,   1,   2,   1,   0
  38,  39,  45,  51,
1373,   1,   2,   1,   0
  45,  39,  40,  51,
```

```
1374,  1,  2,  1,  0
 45, 40, 46, 58,
1375,  1,  2,  1,  0
 40, 47, 46, 58,
1376,  1,  2,  1,  0
 40, 41, 47, 53,
1377,  1,  2,  1,  0
 47, 41, 42, 53,
1378,  1,  2,  1,  0
 47, 42, 48, 60,
1379,  1,  2,  1,  0
 43, 49, 38, 56,
1380,  1,  2,  1,  0
 38, 45, 56, 51,
1381,  1,  2,  1,  0
 45, 51, 40, 58,
1382,  1,  2,  1,  0
 40, 47, 58, 53,
1383,  1,  2,  1,  0
 47, 53, 42, 60,
1384,  1,  2,  1,  0
 43, 55, 49, 56,
1385,  1,  2,  1,  0
 49, 50, 38, 56,
1386,  1,  2,  1,  0
 38, 50, 51, 56,
1387,  1,  2,  1,  0
 45, 56, 51, 57,
1388,  1,  2,  1,  0
 45, 57, 51, 58,
1389,  1,  2,  1,  0
 51, 52, 40, 58,
1390,  1,  2,  1,  0
 40, 52, 53, 58,
1391,  1,  2,  1,  0
 47, 58, 53, 59,
1392,  1,  2,  1,  0
 47, 59, 53, 60,
1393,  1,  2,  1,  0
 53, 54, 42, 60,
1394,  1,  2,  1,  0
 49, 56, 55, 67,
1395,  1,  2,  1,  0
 49, 50, 56, 62,
1396,  1,  2,  1,  0
 56, 50, 51, 62,
1397,  1,  2,  1,  0
 56, 51, 57, 69,
1398,  1,  2,  1,  0
 51, 58, 57, 69,
1399,  1,  2,  1,  0
 51, 52, 58, 64,
1400,  1,  2,  1,  0
 58, 52, 53, 64,
```

```
1401,   1,   2,   1,   0
  58,  53,  59,  71,
1402,   1,   2,   1,   0
  53,  60,  59,  71,
1403,   1,   2,   1,   0
  53,  54,  60,  66,
1404,   1,   2,   1,   0
  49,  56,  67,  62,
1405,   1,   2,   1,   0
  56,  62,  51,  69,
1406,   1,   2,   1,   0
  51,  58,  69,  64,
1407,   1,   2,   1,   0
  58,  64,  53,  71,
1408,   1,   2,   1,   0
  53,  60,  71,  66,
1409,   1,   2,   1,   0
  49,  61,  62,  67,
1410,   1,   2,   1,   0
  56,  67,  62,  68,
1411,   1,   2,   1,   0
  56,  68,  62,  69,
1412,   1,   2,   1,   0
  62,  63,  51,  69,
1413,   1,   2,   1,   0
  51,  63,  64,  69,
1414,   1,   2,   1,   0
  58,  69,  64,  70,
1415,   1,   2,   1,   0
  58,  70,  64,  71,
1416,   1,   2,   1,   0
  64,  65,  53,  71,
1417,   1,   2,   1,   0
  53,  65,  66,  71,
1418,   1,   2,   1,   0
  60,  71,  66,  72,
1419,   4,   1,   4,   0
 112,  34,
1420,   5,   3,   5,   0
  61,  67,
1421,   5,   3,   5,   0
  61,  66,
1422,   5,   3,   5,   0
  72,  67,
1423,   5,   3,   5,   0
  66,  72,
1424,   5,   3,   5,   0
  73,  61,
1425,   5,   3,   5,   0
  67,  95,
1426,   5,   3,   5,   0
  83,  66,
1427,   5,   3,   5,   0
  72, 105,
```

```
1428,   5,   3,   5,   0
 95,  73,
1429,   5,   3,   5,   0
 83,  73,
1430,   5,   3,   5,   0
 95, 105,
1431,   5,   3,   5,   0
 83, 105,
1432,   2,   2,   2,   0
 73,  85,  84, 117,
1433,   2,   2,   2,   0
 95,  84,  85, 117,
1434,   2,   2,   2,   0
 73,  74,  85, 107,
1435,   2,   2,   2,   0
 95,  85,  96, 129,
1436,   2,   2,   2,   0
 85,  74,  75, 107,
1437,   2,   2,   2,   0
 85,  97,  96, 129,
1438,   2,   2,   2,   0
 85,  75,  86, 119,
1439,   2,   2,   2,   0
 85,  86,  97, 119,
1440,   2,   2,   2,   0
 75,  87,  86, 119,
1441,   2,   2,   2,   0
 97,  86,  87, 119,
1442,   2,   2,   2,   0
 75,  76,  87, 109,
1443,   2,   2,   2,   0
 97,  87,  98, 131,
1444,   2,   2,   2,   0
 87,  76,  77, 109,
1445,   2,   2,   2,   0
 87,  99,  98, 131,
1446,   2,   2,   2,   0
 87,  77,  88, 121,
1447,   2,   2,   2,   0
 87,  88,  99, 121,
1448,   2,   2,   2,   0
 77,  89,  88, 121,
1449,   2,   2,   2,   0
 99,  88,  89, 121,
1450,   2,   2,   2,   0
 77,  78,  89, 111,
1451,   2,   2,   2,   0
 99,  89, 100, 133,
1452,   2,   2,   2,   0
 89,  78,  79, 111,
1453,   2,   2,   2,   0
 89, 101, 100, 133,
1454,   2,   2,   2,   0
 89,  79,  90, 123,
```

```
1455,   2,   2,   2,  0
  89,  90, 101, 123,
1456,   2,   2,   2,  0
  79,  91,  90, 123,
1457,   2,   2,   2,  0
 101,  90,  91, 123,
1458,   2,   2,   2,  0
  79,  80,  91, 113,
1459,   2,   2,   2,  0
 101,  91, 102, 135,
1460,   2,   2,   2,  0
  91,  80,  81, 113,
1461,   2,   2,   2,  0
  91, 103, 102, 135,
1462,   2,   2,   2,  0
  91,  81,  92, 125,
1463,   2,   2,   2,  0
  91,  92, 103, 125,
1464,   2,   2,   2,  0
  81,  93,  92, 125,
1465,   2,   2,   2,  0
 103,  92,  93, 125,
1466,   2,   2,   2,  0
  81,  82,  93, 115,
1467,   2,   2,   2,  0
 103,  93, 104, 137,
1468,   2,   2,   2,  0
  93,  82,  83, 115,
1469,   2,   2,   2,  0
  93, 105, 104, 137,
1470,   2,   2,   2,  0
  93,  83,  94, 127,
1471,   2,   2,   2,  0
  93,  94, 105, 127,
1472,   4,   1,   4,  0
   8, 197,
1473,   4,   1,   4,  0
   9, 199,
1474,   4,   1,   4,  0
  11, 181,
1475,   2,   2,   2,  0
  73,  85, 117, 107,
1476,   2,   2,   2,  0
  95, 117,  85, 129,
1477,   2,   2,   2,  0
  85, 107,  75, 119,
1478,   2,   2,   2,  0
  85,  97, 129, 119,
1479,   2,   2,   2,  0
  75,  87, 119, 109,
1480,   2,   2,   2,  0
  97, 119,  87, 131,
1481,   2,   2,   2,  0
  87, 109,  77, 121,
```

```
1482,   2,   2,   2,  0
  87,  99, 131, 121,
1483,   2,   2,   2,  0
  77,  89, 121, 111,
1484,   2,   2,   2,  0
  99, 121,  89, 133,
1485,   2,   2,   2,  0
  89, 111,  79, 123,
1486,   2,   2,   2,  0
  89, 101, 133, 123,
1487,   2,   2,   2,  0
  79,  91, 123, 113,
1488,   2,   2,   2,  0
 101, 123,  91, 135,
1489,   2,   2,   2,  0
  91, 113,  81, 125,
1490,   2,   2,   2,  0
  91, 103, 135, 125,
1491,   2,   2,   2,  0
  81,  93, 125, 115,
1492,   2,   2,   2,  0
 103, 125,  93, 137,
1493,   2,   2,   2,  0
  93, 115,  83, 127,
1494,   2,   2,   2,  0
  93, 105, 137, 127,
1495,   2,   2,   2,  0
  73, 106, 107, 117,
1496,   2,   2,   2,  0
  95, 128, 117, 129,
1497,   2,   2,   2,  0
  85, 117, 107, 118,
1498,   2,   2,   2,  0
 117, 118,  85, 129,
1499,   2,   2,   2,  0
  85, 118, 107, 119,
1500,   2,   2,   2,  0
  85, 118, 119, 129,
1501,   2,   2,   2,  0
 107, 108,  75, 119,
1502,   2,   2,   2,  0
  97, 129, 119, 130,
1503,   2,   2,   2,  0
  75, 108, 109, 119,
1504,   2,   2,   2,  0
  97, 130, 119, 131,
1505,   2,   2,   2,  0
  87, 119, 109, 120,
1506,   2,   2,   2,  0
 119, 120,  87, 131,
1507,   2,   2,   2,  0
  87, 120, 109, 121,
1508,   2,   2,   2,  0
  87, 120, 121, 131,
```

```
1509,   2,   2,   2,   0
 109,  110,   77,  121,
1510,   2,   2,   2,   0
  99,  131,  121,  132,
1511,   2,   2,   2,   0
  77,  110,  111,  121,
1512,   2,   2,   2,   0
  99,  132,  121,  133,
1513,   2,   2,   2,   0
  89,  121,  111,  122,
1514,   2,   2,   2,   0
 121,  122,   89,  133,
1515,   2,   2,   2,   0
  89,  122,  111,  123,
1516,   2,   2,   2,   0
  89,  122,  123,  133,
1517,   2,   2,   2,   0
 111,  112,   79,  123,
1518,   2,   2,   2,   0
 101,  133,  123,  134,
1519,   2,   2,   2,   0
  79,  112,  113,  123,
1520,   2,   2,   2,   0
 101,  134,  123,  135,
1521,   2,   2,   2,   0
  91,  123,  113,  124,
1522,   2,   2,   2,   0
 123,  124,   91,  135,
1523,   2,   2,   2,   0
  91,  124,  113,  125,
1524,   2,   2,   2,   0
  91,  124,  125,  135,
1525,   2,   2,   2,   0
 113,  114,   81,  125,
1526,   2,   2,   2,   0
 103,  135,  125,  136,
1527,   2,   2,   2,   0
  81,  114,  115,  125,
1528,   2,   2,   2,   0
 103,  136,  125,  137,
1529,   2,   2,   2,   0
  93,  125,  115,  126,
1530,   2,   2,   2,   0
 125,  126,   93,  137,
1531,   2,   2,   2,   0
  93,  126,  115,  127,
1532,   2,   2,   2,   0
  93,  126,  127,  137,
1533,   2,   2,   2,   0
 115,  116,   83,  127,
1534,   2,   2,   2,   0
 105,  137,  127,  138,
1535,   4,   1,   4,   0
 180,   35,
```

```
1536,   2,   2,   2,  0
 117, 106, 107, 139,
1537,   2,   2,   2,  0
 117, 129, 128, 161,
1538,   2,   2,   2,  0
 117, 107, 118, 151,
1539,   2,   2,   2,  0
 117, 118, 129, 151,
1540,   2,   2,   2,  0
 107, 119, 118, 151,
1541,   2,   2,   2,  0
 129, 118, 119, 151,
1542,   2,   2,   2,  0
 107, 108, 119, 141,
1543,   2,   2,   2,  0
 129, 119, 130, 163,
1544,   2,   2,   2,  0
 119, 108, 109, 141,
1545,   2,   2,   2,  0
 119, 131, 130, 163,
1546,   2,   2,   2,  0
 119, 109, 120, 153,
1547,   2,   2,   2,  0
 119, 120, 131, 153,
1548,   2,   2,   2,  0
 109, 121, 120, 153,
1549,   2,   2,   2,  0
 131, 120, 121, 153,
1550,   2,   2,   2,  0
 109, 110, 121, 143,
1551,   2,   2,   2,  0
 131, 121, 132, 165,
1552,   2,   2,   2,  0
 121, 110, 111, 143,
1553,   2,   2,   2,  0
 121, 133, 132, 165,
1554,   2,   2,   2,  0
 121, 111, 122, 155,
1555,   2,   2,   2,  0
 121, 122, 133, 155,
1556,   2,   2,   2,  0
 111, 123, 122, 155,
1557,   2,   2,   2,  0
 133, 122, 123, 155,
1558,   2,   2,   2,  0
 111, 112, 123, 145,
1559,   2,   2,   2,  0
 133, 123, 134, 167,
1560,   2,   2,   2,  0
 123, 112, 113, 145,
1561,   2,   2,   2,  0
 123, 135, 134, 167,
1562,   2,   2,   2,  0
 123, 113, 124, 157,
```

```
1563,   2,   2,   2,   0
 123,  124,  135,  157,
1564,   2,   2,   2,   0
 113,  125,  124,  157,
1565,   2,   2,   2,   0
 135,  124,  125,  157,
1566,   2,   2,   2,   0
 113,  114,  125,  147,
1567,   2,   2,   2,   0
 135,  125,  136,  169,
1568,   2,   2,   2,   0
 125,  114,  115,  147,
1569,   2,   2,   2,   0
 125,  137,  136,  169,
1570,   2,   2,   2,   0
 125,  115,  126,  159,
1571,   2,   2,   2,   0
 125,  126,  137,  159,
1572,   2,   2,   2,   0
 115,  127,  126,  159,
1573,   2,   2,   2,   0
 137,  126,  127,  159,
1574,   2,   2,   2,   0
 115,  116,  127,  149,
1575,   2,   2,   2,   0
 137,  127,  138,  171,
1576,   4,   1,   4,   0
  36,  237,
1577,   2,   2,   2,   0
 117,  139,  107,  151,
1578,   2,   2,   2,   0
 117,  129,  161,  151,
1579,   2,   2,   2,   0
 107,  119,  151,  141,
1580,   2,   2,   2,   0
 129,  151,  119,  163,
1581,   2,   2,   2,   0
 119,  141,  109,  153,
1582,   2,   2,   2,   0
 119,  131,  163,  153,
1583,   2,   2,   2,   0
 109,  121,  153,  143,
1584,   2,   2,   2,   0
 131,  153,  121,  165,
1585,   2,   2,   2,   0
 121,  143,  111,  155,
1586,   2,   2,   2,   0
 121,  133,  165,  155,
1587,   2,   2,   2,   0
 111,  123,  155,  145,
1588,   2,   2,   2,   0
 133,  155,  123,  167,
1589,   2,   2,   2,   0
 123,  145,  113,  157,
```

```
1590,   2,   2,   2,  0
 123,  135,  167,  157,
1591,   2,   2,   2,  0
 113,  125,  157,  147,
1592,   2,   2,   2,  0
 135,  157,  125,  169,
1593,   2,   2,   2,  0
 125,  147,  115,  159,
1594,   2,   2,   2,  0
 125,  137,  169,  159,
1595,   2,   2,   2,  0
 115,  127,  159,  149,
1596,   2,   2,   2,  0
 137,  159,  127,  171,
1597,   2,   2,   2,  0
 117,  150,  139,  151,
1598,   2,   2,   2,  0
 117,  150,  151,  161,
1599,   2,   2,   2,  0
 139,  140,  107,  151,
1600,   2,   2,   2,  0
 129,  161,  151,  162,
1601,   2,   2,   2,  0
 107,  140,  141,  151,
1602,   2,   2,   2,  0
 129.  162,  151,  163,
1603,   2,   2,   2,  0
 119,  151,  141,  152,
1604,   2,   2,   2,  0
 151.  152,  119,  163,
1605,   2,   2,   2,  0
 119,  152,  141,  153,
1606,   2,   2,   2,  0
 119.  152,  153,  163,
1607,   2,   2,   2,  0
 141,  142,  109,  153,
1608,   2,   2,   2,  0
 131,  163,  153,  164,
1609,   2,   2,   2,  0
 109.  142,  143,  153,
1610,   2,   2,   2,  0
 131.  164.  153,  165,
1611,   2,   2,   2,  0
 121.  153,  143,  154,
1612,   2,   2,   2,  0
 153.  154.  121,  165,
1613,   2,   2,   2,  0
 121,  154,  143,  155,
1614,   2,   2,   2,  0
 121.  154.  155,  165,
1615,   2,   2,   2,  0
 143,  144,  111,  155,
1616,   2,   2,   2,  0
 133.  165.  155,  166,
```

```
1617,   2,   2,   2,  0
 111, 144, 145, 155,
1618,   2,   2,   2,  0
 133, 166, 155, 167,
1619,   2,   2,   2,  0
 123, 155, 145, 156,
1620,   2,   2,   2,  0
 155, 156, 123, 167,
1621,   2,   2,   2,  0
 123, 156, 145, 157,
1622,   2,   2,   2,  0
 123, 156, 157, 167,
1623,   2,   2,   2,  0
 145, 146, 113, 157,
1624,   2,   2,   2,  0
 135, 167, 157, 168,
1625,   2,   2,   2,  0
 113, 146, 147, 157,
1626,   2,   2,   2,  0
 135, 168, 157, 169,
1627,   2,   2,   2,  0
 125, 157, 147, 158,
1628,   2,   2,   2,  0
 157, 158, 125, 169,
1629,   2,   2,   2,  0
 125, 158, 147, 159,
1630,   2,   2,   2,  0
 125, 158, 159, 169,
1631,   2,   2,   2,  0
 147, 148, 115, 159,
1632,   2,   2,   2,  0
 137, 169, 159, 170,
1633,   2,   2,   2,  0
 115, 148, 149, 159,
1634,   2,   2,   2,  0
 137, 170, 159, 171,
1635,   2,   2,   2,  0
 127, 159, 149, 160,
1636,   2,   2,   2,  0
 159, 160, 127, 171,
1637,   2,   2,   2,  0
 139, 151, 150, 183,
1638,   2,   2,   2,  0
 161, 150, 151, 183,
1639,   2,   2,   2,  0
 139, 140, 151, 173,
1640,   2,   2,   2,  0
 161, 151, 162, 195,
1641,   2,   2,   2,  0
 151, 140, 141, 173,
1642,   2,   2,   2,  0
 151, 163, 162, 195,
1643,   2,   2,   2,  0
 151, 141, 152, 185,
```

```
1644,   2,   2,   2,   0
 151, 152, 163, 185,
1645,   2,   2,   2,   0
 141, 153, 152, 185,
1646,   2,   2,   2,   0
 163, 152, 153, 185,
1647,   2,   2,   2,   0
 141, 142, 153, 175,
1648,   2,   2,   2,   0
 163, 153, 164, 197,
1649,   2,   2,   2,   0
 153, 142, 143, 175,
1650,   2,   2,   2,   0
 153, 165, 164, 197,
1651,   2,   2,   2,   0
 153, 143, 154, 187,
1652,   2,   2,   2,   0
 153, 154, 165, 187,
1653,   2,   2,   2,   0
 143, 155, 154, 187,
1654,   2,   2,   2,   0
 165, 154, 155, 187,
1655,   2,   2,   2,   0
 143, 144, 155, 177,
1656,   2,   2,   2,   0
 165, 155, 166, 199,
1657,   2,   2,   2,   0
 155, 144, 145, 177,
1658,   2,   2,   2,   0
 155, 167, 166, 199,
1659,   2,   2,   2,   0
 155, 145, 156, 189,
1660,   2,   2,   2,   0
 155, 156, 167, 189,
1661,   2,   2,   2,   0
 145, 157, 156, 189,
1662,   2,   2,   2,   0
 167, 156, 157, 189,
1663,   2,   2,   2,   0
 145, 146, 157, 179,
1664,   2,   2,   2,   0
 167, 157, 168, 201,
1665,   2,   2,   2,   0
 157, 146, 147, 179,
1666,   2,   2,   2,   0
 157, 169, 168, 201,
1667,   2,   2,   2,   0
 157, 147, 158, 191,
1668,   2,   2,   2,   0
 157, 158, 169, 191,
1669,   2,   2,   2,   0
 147, 159, 158, 191,
1670,   2,   2,   2,   0
 169, 158, 159, 191,
```

```
1671,   2,   2,   2,  0
 147, 148, 159, 181,
1672,   2,   2,   2,  0
 169, 159, 170, 203,
1673,   2,   2,   2,  0
 159, 148, 149, 181,
1674,   2,   2,   2,  0
 159, 171, 170, 203,
1675,   2,   2,   2,  0
 159, 149, 160, 193,
1676,   2,   2,   2,  0
 159, 160, 171, 193,
1677,   4,   1,   4,  0
 275,  27,
1678,   2,   2,   2,  0
 139, 151, 183, 173,
1679,   2,   2,   2,  0
 161, 183, 151, 195,
1680,   2,   2,   2,  0
 151, 173, 141, 185,
1681,   2,   2,   2,  0
 151, 163, 195, 185,
1682,   2,   2,   2,  0
 141, 153, 185, 175,
1683,   2,   2,   2,  0
 163, 185, 153, 197,
1684,   2,   2,   2,  0
 153, 175, 143, 187,
1685,   2,   2,   2,  0
 153, 165, 197, 187,
1686,   2,   2,   2,  0
 143, 155, 187, 177,
1687,   2,   2,   2,  0
 165, 187, 155, 199,
1688,   2,   2,   2,  0
 155, 177, 145, 189,
1689,   2,   2,   2,  0
 155, 167, 199, 189,
1690,   2,   2,   2,  0
 145, 157, 189, 179,
1691,   2,   2,   2,  0
 167, 189, 157, 201,
1692,   2,   2,   2,  0
 157, 179, 147, 191,
1693,   2,   2,   2,  0
 157, 169, 201, 191,
1694,   2,   2,   2,  0
 147, 159, 191, 181,
1695,   2,   2,   2,  0
 169, 191, 159, 203,
1696,   2,   2,   2,  0
 159, 181, 149, 193,
1697,   2,   2,   2,  0
 159, 171, 203, 193,
```

```
1698,   2,   2,   2,  0
 139, 172, 173, 183,
1699,   2,   2,   2,  0
 161, 194, 183, 195,
1700,   2,   2,   2,  0
 151, 183, 173, 184,
1701,   2,   2,   2,  0
 183, 184, 151, 195,
1702,   2,   2,   2,  0
 151, 184, 173, 185,
1703,   2,   2,   2,  0
 151, 184, 185, 195,
1704,   2,   2,   2,  0
 173, 174, 141, 185,
1705,   2,   2,   2,  0
 163, 195, 185, 196,
1706,   2,   2,   2,  0
 141, 174, 175, 185,
1707,   2,   2,   2,  0
 163, 196, 185, 197,
1708,   2,   2,   2,  0
 153, 185, 175, 186,
1709,   2,   2,   2,  0
 185, 186, 153, 197,
1710,   2,   2,   2,  0
 153, 186, 175, 187,
1711,   2,   2,   2,  0
 153, 186, 187, 197,
1712,   2,   2,   2,  0
 175, 176, 143, 187,
1713,   2,   2,   2,  0
 165, 197, 187, 198,
1714,   2,   2,   2,  0
 143, 176, 177, 187,
1715,   2,   2,   2,  0
 165, 198, 187, 199,
1716,   2,   2,   2,  0
 155, 187, 177, 188,
1717,   2,   2,   2,  0
 187, 188, 155, 199,
1718,   2,   2,   2,  0
 155, 188, 177, 189,
1719,   2,   2,   2,  0
 155, 188, 189, 199,
1720,   2,   2,   2,  0
 177, 178, 145, 189,
1721,   2,   2,   2,  0
 167, 199, 189, 200,
1722,   2,   2,   2,  0
 145, 178, 179, 189,
1723,   2,   2,   2,  0
 167, 200, 189, 201,
1724,   2,   2,   2,  0
 157, 189, 179, 190,
```

```
1725,   2,   2,   2,  0
 189, 190, 157, 201,
1726,   2,   2,   2,  0
 157, 190, 179, 191,
1727,   2,   2,   2,  0
 157, 190, 191, 201,
1728,   2,   2,   2,  0
 179, 180, 147, 191,
1729,   2,   2,   2,  0
 169, 201, 191, 202,
1730,   2,   2,   2,  0
 147, 180, 181, 191,
1731,   2,   2,   2,  0
 169, 202, 191, 203,
1732,   2,   2,   2,  0
 159, 191, 181, 192,
1733,   2,   2,   2,  0
 191, 192, 159, 203,
1734,   2,   2,   2,  0
 159, 192, 181, 193,
1735,   2,   2,   2,  0
 159, 192, 193, 203,
1736,   2,   2,   2,  0
 181, 182, 149, 193,
1737,   2,   2,   2,  0
 171, 203, 193, 204,
1738,   2,   2,   2,  0
 183, 172, 173, 205,
1739,   2,   2,   2,  0
 183, 195, 194, 227,
1740,   2,   2,   2,  0
 183, 173, 184, 217,
1741,   2,   2,   2,  0
 183, 184, 195, 217,
1742,   2,   2,   2,  0
 173, 185, 184, 217,
1743,   2,   2,   2,  0
 195, 184, 185, 217,
1744,   2,   2,   2,  0
 173, 174, 185, 207,
1745,   2,   2,   2,  0
 195, 185, 196, 229,
1746,   2,   2,   2,  0
 185, 174, 175, 207,
1747,   2,   2,   2,  0
 185, 197, 196, 229,
1748,   2,   2,   2,  0
 185, 175, 186, 219,
1749,   2,   2,   2,  0
 185, 186, 197, 219,
1750,   2,   2,   2,  0
 175, 187, 186, 219,
1751,   2,   2,   2,  0
 197, 186, 187, 219,
```

```
1752,   2,   2,   2,   0
 175, 176, 187, 209,
1753,   2,   2,   2,   0
 197, 187, 198, 231,
1754,   2,   2,   2,   0
 187, 176, 177, 209,
1755,   2,   2,   2,   0
 187, 199, 198, 231,
1756,   2,   2,   2,   0
 187, 177, 188, 221,
1757,   2,   2,   2,   0
 187, 188, 199, 221,
1758,   2,   2,   2,   0
 177, 189, 188, 221,
1759,   2,   2,   2,   0
 199, 188, 189, 221,
1760,   2,   2,   2,   0
 177, 178, 189, 211,
1761,   2,   2,   2,   0
 199, 189, 200, 233,
1762,   2,   2,   2,   0
 189, 178, 179, 211,
1763,   2,   2,   2,   0
 189, 201, 200, 233,
1764,   2,   2,   2,   0
 189, 179, 190, 223,
1765,   2,   2,   2,   0
 189, 190, 201, 223,
1766,   2,   2,   2,   0
 179, 191, 190, 223,
1767,   2,   2,   2,   0
 201, 190, 191, 223,
1768,   2,   2,   2,   0
 179, 180, 191, 213,
1769,   2,   2,   2,   0
 201, 191, 202, 235,
1770,   2,   2,   2,   0
 191, 180, 181, 213,
1771,   2,   2,   2,   0
 191, 203, 202, 235,
1772,   2,   2,   2,   0
 191, 181, 192, 225,
1773,   2,   2,   2,   0
 191, 192, 203, 225,
1774,   2,   2,   2,   0
 181, 193, 192, 225,
1775,   2,   2,   2,   0
 203, 192, 193, 225,
1776,   2,   2,   2,   0
 181, 182, 193, 215,
1777,   2,   2,   2,   0
 203, 193, 204, 237,
1778,   2,   2,   2,   0
 183, 205, 173, 217,
```

```
1779,   2,   2,   2,   0
 183, 195, 227, 217,
1780,   2,   2,   2,   0
 173, 185, 217, 207,
1781,   2,   2,   2,   0
 195, 217, 185, 229,
1782,   2,   2,   2,   0
 185, 207, 175, 219,
1783,   2,   2,   2,   0
 185, 197, 229, 219,
1784,   2,   2,   2,   0
 175, 187, 219, 209,
1785,   2,   2,   2,   0
 197, 219, 187, 231,
1786,   2,   2,   2,   0
 187, 209, 177, 221,
1787,   2,   2,   2,   0
 187, 199, 231, 221,
1788,   2,   2,   2,   0
 177, 189, 221, 211,
1789,   2,   2,   2,   0
 199, 221, 189, 233,
1790,   2,   2,   2,   0
 189, 211, 179, 223,
1791,   2,   2,   2,   0
 189, 201, 233, 223,
1792,   2,   2,   2,   0
 179, 191, 223, 213,
1793,   2,   2,   2,   0
 201, 223, 191, 235,
1794,   2,   2,   2,   0
 191, 213, 181, 225,
1795,   2,   2,   2,   0
 191, 203, 235, 225,
1796,   2,   2,   2,   0
 181, 193, 225, 215,
1797,   2,   2,   2,   0
 203, 225, 193, 237,
1798,   2,   2,   2,   0
 183, 216, 205, 217,
1799,   2,   2,   2,   0
 183, 216, 217, 227,
1800,   2,   2,   2,   0
 205, 206, 173, 217,
1801,   2,   2,   2,   0
 195, 227, 217, 228,
1802,   2,   2,   2,   0
 173, 206, 207, 217,
1803,   2,   2,   2,   0
 195, 228, 217, 229,
1804,   2,   2,   2,   0
 185, 217, 207, 218,
1805,   2,   2,   2,   0
 217, 218, 185, 229,
```

```
1806,   2,   2,   2,   0
 185, 218, 207, 219,
1807,   2,   2,   2,   0
 185, 218, 219, 229,
1808,   2,   2,   2,   0
 207, 208, 175, 219,
1809,   2,   2,   2,   0
 197, 229, 219, 230,
1810,   2,   2,   2,   0
 175, 208, 209, 219,
1811,   2,   2,   2,   0
 197, 230, 219, 231,
1812,   2,   2,   2,   0
 187, 219, 209, 220,
1813,   2,   2,   2,   0
 219, 220, 187, 231,
1814,   2,   2,   2,   0
 187, 220, 209, 221,
1815,   2,   2,   2,   0
 187, 220, 221, 231,
1816,   2,   2,   2,   0
 209, 210, 177, 221,
1817,   2,   2,   2,   0
 199, 231, 221, 232,
1818,   2,   2,   2,   0
 177, 210, 211, 221,
1819,   2,   2,   2,   0
 199, 232, 221, 233,
1820,   2,   2,   2,   0
 189, 221, 211, 222,
1821,   2,   2,   2,   0
 221, 222, 189, 233,
1822,   2,   2,   2,   0
 189, 222, 211, 223,
1823,   2,   2,   2,   0
 189, 222, 223, 233,
1824,   2,   2,   2,   0
 211, 212, 179, 223,
1825,   2,   2,   2,   0
 201, 233, 223, 234,
1826,   2,   2,   2,   0
 179, 212, 213, 223,
1827,   2,   2,   2,   0
 201, 234, 223, 235,
1828,   2,   2,   2,   0
 191, 223, 213, 224,
1829,   2,   2,   2,   0
 223, 224, 191, 235,
1830,   2,   2,   2,   0
 191, 224, 213, 225,
1831,   2,   2,   2,   0
 191, 224, 225, 235,
1832,   2,   2,   2,   0
 213, 214, 181, 225,
```

```
1833,   2,   2,   2,  0
 203, 235, 225, 236,
1834,   2,   2,   2,  0
 181, 214, 215, 225,
1835,   2,   2,   2,  0
 203, 236, 225, 237,
1836,   2,   2,   2,  0
 193, 225, 215, 226,
1837,   2,   2,   2,  0
 225, 226, 193, 237,
1838,   2,   2,   2,  0
 205, 217, 216, 249,
1839,   2,   2,   2,  0
 227, 216, 217, 249,
1840,   2,   2,   2,  0
 205, 206, 217, 239,
1841,   2,   2,   2,  0
 227, 217, 228, 261,
1842,   2,   2,   2,  0
 217, 206, 207, 239,
1843,   2,   2,   2,  0
 217, 229, 228, 261,
1844,   2,   2,   2,  0
 217, 207, 218, 251,
1845,   2,   2,   2,  0
 217, 218, 229, 251,
1846,   2,   2,   2,  0
 207, 219, 218, 251,
1847,   2,   2,   2,  0
 229, 218, 219, 251,
1848,   2,   2,   2,  0
 207, 208, 219, 241,
1849,   2,   2,   2,  0
 229, 219, 230, 263,
1850,   2,   2,   2,  0
 219, 208, 209, 241,
1851,   2,   2,   2,  0
 219, 231, 230, 263,
1852,   2,   2,   2,  0
 219, 209, 220, 253,
1853,   2,   2,   2,  0
 219, 220, 231, 253,
1854,   2,   2,   2,  0
 209, 221, 220, 253,
1855,   2,   2,   2,  0
 231, 220, 221, 253,
1856,   2,   2,   2,  0
 209, 210, 221, 243,
1857,   2,   2,   2,  0
 231, 221, 232, 265,
1858,   2,   2,   2,  0
 221, 210, 211, 243,
1859,   2,   2,   2,  0
 221, 233, 232, 265,
```

```
1860,   2,   2,   2,   0
 221,  211,  222,  255,
1861,   2,   2,   2,   0
 221,  222,  233,  255,
1862,   2,   2,   2,   0
 211,  223,  222,  255,
1863,   2,   2,   2,   0
 233,  222,  223,  255,
1864,   2,   2,   2,   0
 211,  212,  223,  245,
1865,   2,   2,   2,   0
 233,  223,  234,  267,
1866,   2,   2,   2,   0
 223,  212,  213,  245,
1867,   2,   2,   2,   0
 223,  235,  234,  267,
1868,   2,   2,   2,   0
 223,  213,  224,  257,
1869,   2,   2,   2,   0
 223,  224,  235,  257,
1870,   2,   2,   2,   0
 213,  225,  224,  257,
1871,   2,   2,   2,   0
 235,  224,  225,  257,
1872,   2,   2,   2,   0
 213,  214,  225,  247,
1873,   2,   2,   2,   0
 235,  225,  236,  269,
1874,   2,   2,   2,   0
 225,  214,  215,  247,
1875,   2,   2,   2,   0
 225,  237,  236,  269,
1876,   2,   2,   2,   0
 225,  215,  226,  259,
1877,   2,   2,   2,   0
 225,  226,  237,  259,
1878,   2,   2,   2,   0
 205,  217,  249,  239,
1879,   2,   2,   2,   0
 227,  249,  217,  261,
1880,   2,   2,   2,   0
 217,  239,  207,  251,
1881,   2,   2,   2,   0
 217,  229,  261,  251,
1882,   2,   2,   2,   0
 207,  219,  251,  241,
1883,   2,   2,   2,   0
 229,  251,  219,  263,
1884,   2,   2,   2,   0
 219,  241,  209,  253,
1885,   2,   2,   2,   0
 219,  231,  263,  253,
1886,   2,   2,   2,   0
 209,  221,  253,  243,
```

```
1887,   2,   2,   2,   0
 231,  253,  221,  265,
1888,   2,   2,   2,   0
 221,  243,  211,  255,
1889,   2,   2,   2,   0
 221,  233,  265,  255,
1890,   2,   2,   2,   0
 211,  223,  255,  245,
1891,   2,   2,   2,   0
 233,  255,  223,  267,
1892,   2,   2,   2,   0
 223,  245,  213,  257,
1893,   2,   2,   2,   0
 223,  235,  267,  257,
1894,   2,   2,   2,   0
 213,  225,  257,  247,
1895,   2,   2,   2,   0
 235,  257,  225,  269,
1896,   2,   2,   2,   0
 225,  247,  215,  259,
1897,   2,   2,   2,   0
 225,  237,  269,  259,
1898,   4,   1,   4,   0
  31,  472,
1899,   2,   2,   2,   0
 205,  238,  239,  249,
1900,   2,   2,   2,   0
 227,  260,  249,  261,
1901,   2,   2,   2,   0
 217,  249,  239,  250,
1902,   2,   2,   2,   0
 249,  250,  217,  261,
1903,   2,   2,   2,   0
 217,  250,  239,  251,
1904,   2,   2,   2,   0
 217,  250,  251,  261,
1905,   2,   2,   2,   0
 239,  240,  207,  251,
1906,   2,   2,   2,   0
 229,  261,  251,  262,
1907,   2,   2,   2,   0
 207,  240,  241,  251,
1908,   2,   2,   2,   0
 229,  262,  251,  263,
1909,   2,   2,   2,   0
 219,  251,  241,  252,
1910,   2,   2,   2,   0
 251,  252,  219,  263,
1911,   2,   2,   2,   0
 219,  252,  241,  253,
1912,   2,   2,   2,   0
 219,  252,  253,  263,
1913,   2,   2,   2,   0
 241,  242,  209,  253,
```

```
1914,   2,   2,   2,   0
 231,  263,  253,  264,
1915,   2,   2,   2,   0
 209,  242,  243,  253,
1916,   2,   2,   2,   0
 231,  264,  253,  265,
1917,   2,   2,   2,   0
 221,  253,  243,  254,
1918,   2,   2,   2,   0
 253,  254,  221,  265,
1919,   2,   2,   2,   0
 221,  254,  243,  255,
1920,   2,   2,   2,   0
 221,  254,  255,  265,
1921,   2,   2,   2,   0
 243,  244,  211,  255,
1922,   2,   2,   2,   0
 233,  265,  255,  266,
1923,   2,   2,   2,   0
 211,  244,  245,  255,
1924,   2,   2,   2,   0
 233,  266,  255,  267,
1925,   2,   2,   2,   0
 223,  255,  245,  256,
1926,   2,   2,   2,   0
 255,  256,  223,  267,
1927,   2,   2,   2,   0
 223,  256,  245,  257,
1928,   2,   2,   2,   0
 223,  256,  257,  267,
1929,   2,   2,   2,   0
 245,  246,  213,  257,
1930,   2,   2,   2,   0
 235,  267,  257,  268,
1931,   2,   2,   2,   0
 213,  246,  247,  257,
1932,   2,   2,   2,   0
 235,  268,  257,  269,
1933,   2,   2,   2,   0
 225,  257,  247,  258,
1934,   2,   2,   2,   0
 257,  258,  225,  269,
1935,   2,   2,   2,   0
 225,  258,  247,  259,
1936,   2,   2,   2,   0
 225,  258,  259,  269,
1937,   2,   2,   2,   0
 247,  248,  215,  259,
1938,   2,   2,   2,   0
 237,  269,  259,  270,
1939,   4,   1,   4,   0
 491,   38,
1940,   4,   1,   4,   0
 474,   57,
```

```
1941,   4,   1,   4,   0
 426,  76,
1942,   2,   2,   2,   0
 249, 238, 239, 271,
1943,   2,   2,   2,   0
 249, 261, 260, 293,
1944,   2,   2,   2,   0
 249, 239, 250, 283,
1945,   2,   2,   2,   0
 249, 250, 261, 283,
1946,   2,   2,   2,   0
 239, 251, 250, 283,
1947,   2,   2,   2,   0
 261, 250, 251, 283,
1948,   2,   2,   2,   0
 239, 240, 251, 273,
1949,   2,   2,   2,   0
 261, 251, 262, 295,
1950,   2,   2,   2,   0
 251, 240, 241, 273,
1951,   2,   2,   2,   0
 251, 263, 262, 295,
1952,   2,   2,   2,   0
 251, 241, 252, 285,
1953,   2,   2,   2,   0
 251, 252, 263, 285,
1954,   2,   2,   2,   0
 241, 253, 252, 285,
1955,   2,   2,   2,   0
 263, 252, 253, 285,
1956,   2,   2,   2,   0
 241, 242, 253, 275,
1957,   2,   2,   2,   0
 263, 253, 264, 297,
1958,   2,   2,   2,   0
 253, 242, 243, 275,
1959,   2,   2,   2,   0
 253, 265, 264, 297,
1960,   2,   2,   2,   0
 253, 243, 254, 287,
1961,   2,   2,   2,   0
 253, 254, 265, 287,
1962,   2,   2,   2,   0
 243, 255, 254, 287,
1963,   2,   2,   2,   0
 265, 254, 255, 287,
1964,   2,   2,   2,   0
 243, 244, 255, 277,
1965,   2,   2,   2,   0
 265, 255, 266, 299,
1966,   2,   2,   2,   0
 255, 244, 245, 277,
1967,   2,   2,   2,   0
 255, 267, 266, 299,
```

```
1968,   2,   2,   2,   0
 255, 245, 256, 289,
1969,   2,   2,   2,   0
 255, 256, 267, 289,
1970,   2,   2,   2,   0
 245, 257, 256, 289,
1971,   2,   2,   2,   0
 267, 256, 257, 289,
1972,   2,   2,   2,   0
 245, 246, 257, 279,
1973,   2,   2,   2,   0
 267, 257, 268, 301,
1974,   2,   2,   2,   0
 257, 246, 247, 279,
1975,   2,   2,   2,   0
 257, 269, 268, 301,
1976,   2,   2,   2,   0
 257, 247, 258, 291,
1977,   2,   2,   2,   0
 257, 258, 269, 291,
1978,   2,   2,   2,   0
 247, 259, 258, 291,
1979,   2,   2,   2,   0
 269, 258, 259, 291,
1980,   2,   2,   2,   0
 247, 248, 259, 281,
1981,   2,   2,   2,   0
 269, 259, 270, 303,
1982,   2,   2,   2,   0
 249, 271, 239, 283,
1983,   2,   2,   2,   0
 249, 261, 293, 283,
1984,   2,   2,   2,   0
 239, 251, 283, 273,
1985,   2,   2,   2,   0
 261, 283, 251, 295,
1986,   2,   2,   2,   0
 251, 273, 241, 285,
1987,   2,   2,   2,   0
 251, 263, 295, 285,
1988,   2,   2,   2,   0
 241, 253, 285, 275,
1989,   2,   2,   2,   0
 263, 285, 253, 297,
1990,   2,   2,   2,   0
 253, 275, 243, 287,
1991,   2,   2,   2,   0
 253, 265, 297, 287,
1992,   2,   2,   2,   0
 243, 255, 287, 277,
1993,   2,   2,   2,   0
 265, 287, 255, 299,
1994,   2,   2,   2,   0
 255, 277, 245, 289,
```

```
1995,   2,   2,   2,   0
 255,  267,  299,  289,
1996,   2,   2,   2,   0
 245,  257,  289,  279,
1997,   2,   2,   2,   0
 267,  289,  257,  301,
1998,   2,   2,   2,   0
 257,  279,  247,  291,
1999,   2,   2,   2,   0
 257,  269,  301,  291,
2000,   2,   2,   2,   0
 247,  259,  291,  281,
2001,   2,   2,   2,   0
 269,  291,  259,  303,
2002,   2,   2,   2,   0
 249,  282,  271,  283,
2003,   2,   2,   2,   0
 249,  282,  283,  293,
2004,   2,   2,   2,   0
 271,  272,  239,  283,
2005,   2,   2,   2,   0
 261,  293,  283,  294,
2006,   2,   2,   2,   0
 239,  272,  273,  283,
2007,   2,   2,   2,   0
 261,  294,  283,  295,
2008,   2,   2,   2,   0
 251,  283,  273,  284,
2009,   2,   2,   2,   0
 283,  284,  251,  295,
2010,   2,   2,   2,   0
 251,  284,  273,  285,
2011,   2,   2,   2,   0
 251,  284,  285,  295,
2012,   2,   2,   2,   0
 273,  274,  241,  285,
2013,   2,   2,   2,   0
 263,  295,  285,  296,
2014,   2,   2,   2,   0
 241,  274,  275,  285,
2015,   2,   2,   2,   0
 263,  296,  285,  297,
2016,   2,   2,   2,   0
 253,  285,  275,  286,
2017,   2,   2,   2,   0
 285,  286,  253,  297,
2018,   2,   2,   2,   0
 253,  286,  275,  287,
2019,   2,   2,   2,   0
 253,  286,  287,  297,
2020,   2,   2,   2,   0
 275,  276,  243,  287,
2021,   2,   2,   2,   0
 265,  297,  287,  298,
```

```
2022,   2,   2,   2,   0
 243,  276,  277,  287,
2023,   2,   2,   2,   0
 265,  298,  287,  299,
2024,   2,   2,   2,   0
 255,  287,  277,  288,
2025,   2,   2,   2,   0
 287,  288,  255,  299,
2026,   2,   2,   2,   0
 255,  288,  277,  289,
2027,   2,   2,   2,   0
 255,  288,  289,  299,
2028,   2,   2,   2,   0
 277,  278,  245,  289,
2029,   2,   2,   2,   0
 267,  299,  289,  300,
2030,   2,   2,   2,   0
 245,  278,  279,  289,
2031,   2,   2,   2,   0
 267,  300,  289,  301,
2032,   2,   2,   2,   0
 257,  289,  279,  290,
2033,   2,   2,   2,   0
 289,  290,  257,  301,
2034,   2,   2,   2,   0
 257,  290,  279,  291,
2035,   2,   2,   2,   0
 257,  290,  291,  301,
2036,   2,   2,   2,   0
 279,  280,  247,  291,
2037,   2,   2,   2,   0
 269,  301,  291,  302,
2038,   2,   2,   2,   0
 247,  280,  281,  291,
2039,   2,   2,   2,   0
 269,  302,  291,  303,
2040,   2,   2,   2,   0
 259,  291,  281,  292,
2041,   2,   2,   2,   0
 291,  292,  259,  303,
2042,   2,   2,   2,   0
 271,  283,  282,  315,
2043,   2,   2,   2,   0
 293,  282,  283,  315,
2044,   2,   2,   2,   0
 271,  272,  283,  305,
2045,   2,   2,   2,   0
 293,  283,  294,  327,
2046,   2,   2,   2,   0
 283,  272,  273,  305,
2047,   2,   2,   2,   0
 283,  295,  294,  327,
2048,   2,   2,   2,   0
 283,  273,  284,  317,
```

```
2049,   2,   2,   2,   0
 283,  284,  295,  317,
2050,   2,   2,   2,   0
 273,  285,  284,  317,
2051,   2,   2,   2,   0
 295,  284,  285,  317,
2052,   2,   2,   2,   0
 273,  274,  285,  307,
2053,   2,   2,   2,   0
 295,  285,  296,  329,
2054,   2,   2,   2,   0
 285,  274,  275,  307,
2055,   2,   2,   2,   0
 285,  297,  296,  329,
2056,   2,   2,   2,   0
 285,  275,  286,  319,
2057,   2,   2,   2,   0
 285,  286,  297,  319,
2058,   2,   2,   2,   0
 275,  287,  286,  319,
2059,   2,   2,   2,   0
 297,  286,  287,  319,
2060,   2,   2,   2,   0
 275,  276,  287,  309,
2061,   2,   2,   2,   0
 297,  287,  298,  331,
2062,   2,   2,   2,   0
 287,  276,  277,  309,
2063,   2,   2,   2,   0
 287,  299,  298,  331,
2064,   2,   2,   2,   0
 287,  277,  288,  321,
2065,   2,   2,   2,   0
 287,  288,  299,  321,
2066,   2,   2,   2,   0
 277,  289,  288,  321,
2067,   2,   2,   2,   0
 299,  288,  289,  321,
2068,   2,   2,   2,   0
 277,  278,  289,  311,
2069,   2,   2,   2,   0
 299,  289,  300,  333,
2070,   2,   2,   2,   0
 289,  278,  279,  311,
2071,   2,   2,   2,   0
 289,  301,  300,  333,
2072,   2,   2,   2,   0
 289,  279,  290,  323,
2073,   2,   2,   2,   0
 289,  290,  301,  323,
2074,   2,   2,   2,   0
 279,  291,  290,  323,
2075,   2,   2,   2,   0
 301,  290,  291,  323,
```

```
2076,   2,    2,    2,    0
 279,  280,  291,  313,
2077,   2,    2,    2,    0
 301,  291,  302,  335,
2078,   2,    2,    2,    0
 291,  280,  281,  313,
2079,   2,    2,    2,    0
 291,  303,  302,  335,
2080,   2,    2,    2,    0
 291,  281,  292,  325,
2081,   2,    2,    2,    0
 291,  292,  303,  325,
2082,   2,    2,    2,    0
 271,  283,  315,  305,
2083,   2,    2,    2,    0
 293,  315,  283,  327,
2084,   2,    2,    2,    0
 283,  305,  273,  317,
2085,   2,    2,    2,    0
 283,  295,  327,  317,
2086,   2,    2,    2,    0
 273,  285,  317,  307,
2087,   2,    2,    2,    0
 295,  317,  285,  329,
2088,   2,    2,    2,    0
 285,  307,  275,  319,
2089,   2,    2,    2,    0
 285,  297,  329,  319,
2090,   2,    2,    2,    0
 275,  287,  319,  309,
2091,   2,    2,    2,    0
 297,  319,  287,  331,
2092,   2,    2,    2,    0
 287,  309,  277,  321,
2093,   2,    2,    2,    0
 287,  299,  331,  321,
2094,   2,    2,    2,    0
 277,  289,  321,  311,
2095,   2,    2,    2,    0
 299,  321,  289,  333,
2096,   2,    2,    2,    0
 289,  311,  279,  323,
2097,   2,    2,    2,    0
 289,  301,  333,  323,
2098,   2,    2,    2,    0
 279,  291,  323,  313,
2099,   2,    2,    2,    0
 301,  323,  291,  335,
2100,   2,    2,    2,    0
 291,  313,  281,  325,
2101,   2,    2,    2,    0
 291,  303,  335,  325,
2102,   2,    2,    2,    0
 271,  304,  305,  315,
```

```
2103,   2,   2,   2,   0
 293,  326,  315,  327,
2104,   2,   2,   2,   0
 283,  315,  305,  316,
2105,   2,   2,   2,   0
 315,  316,  283,  327,
2106,   2,   2,   2,   0
 283,  316,  305,  317,
2107,   2,   2,   2,   0
 283,  316,  317,  327,
2108,   2,   2,   2,   0
 305,  306,  273,  317,
2109,   2,   2,   2,   0
 295,  327,  317,  328,
2110,   2,   2,   2,   0
 273,  306,  307,  317,
2111,   2,   2,   2,   0
 295,  328,  317,  329,
2112,   2,   2,   2,   0
 285,  317,  307,  318,
2113,   2,   2,   2.   0
 317,  318,  285,  329,
2114,   2,   2,   2,   0
 285,  318,  307,  319,
2115,   2,   2,   2,   0
 285,  318,  319,  329,
2116,   2,   2,   2,   0
 307,  308,  275,  319,
2117,   2,   2,   2,   0
 297,  329,  319,  330,
2118,   2,   2,   2,   0
 275,  308,  309,  319,
2119,   2,   2,   2,   0
 297,  330,  319,  331,
2120,   2,   2,   2,   0
 287,  319,  309,  320,
2121,   2,   2,   2,   0
 319,  320,  287,  331,
2122,   2,   2,   2,   0
 287,  320,  309,  321,
2123,   2,   2,   2,   0
 287,  320,  321,  331,
2124,   2,   2,   2,   0
 309,  310,  277,  321,
2125,   2,   2,   2,   0
 299,  331,  321,  332,
2126,   2,   2,   2,   0
 277,  310,  311,  321,
2127,   2,   2,   2,   0
 299,  332,  321,  333,
2128,   2,   2,   2,   0
 289,  321,  311,  322,
2129,   2,   2,   2,   0
 321,  322,  289,  333,
```

```
2130,   2,   2,   2,   0
 289, 322, 311, 323,
2131,   2,   2,   2,   0
 289, 322, 323, 333,
2132,   2,   2,   2,   0
 311, 312, 279, 323,
2133,   2,   2,   2,   0
 301, 333, 323, 334,
2134,   2,   2,   2,   0
 279, 312, 313, 323,
2135,   2,   2,   2,   0
 301, 334, 323, 335,
2136,   2,   2,   2,   0
 291, 323, 313, 324,
2137,   2,   2,   2,   0
 323, 324, 291, 335,
2138,   2,   2,   2,   0
 291, 324, 313, 325,
2139,   2,   2,   2,   0
 291, 324, 325, 335,
2140,   2,   2,   2,   0
 313, 314, 281, 325,
2141,   2,   2,   2,   0
 303, 335, 325, 336,
2142,   4,   1,   4,   0
 430, 232,
2143,   4,   1,   4,   0
 432, 212,
2144,   2,   2,   2,   0
 315, 304, 305, 337,
2145,   2,   2,   2,   0
 315, 327, 326, 359,
2146,   2,   2,   2,   0
 315, 305, 316, 349,
2147,   2,   2,   2,   0
 315, 316, 327, 349,
2148,   2,   2,   2,   0
 305, 317, 316, 349,
2149,   2,   2,   2,   0
 327, 316, 317, 349,
2150,   2,   2,   2,   0
 305, 306, 317, 339,
2151,   2,   2,   2,   0
 327, 317, 328, 361,
2152,   2,   2,   2,   0
 317, 306, 307, 339,
2153,   2,   2,   2,   0
 317, 329, 328, 361,
2154,   2,   2,   2,   0
 317, 307, 318, 351,
2155,   2,   2,   2,   0
 317, 318, 329, 351,
2156,   2,   2,   2,   0
 307, 319, 318, 351,
```

```
2157,   2,   2,   2,   0
 329, 318, 319, 351,
2158,   2,   2,   2,   0
 307, 308, 319, 341,
2159,   2,   2,   2,   0
 329, 319, 330, 363,
2160,   2,   2,   2,   0
 319, 308, 309, 341,
2161,   2,   2,   2,   0
 319, 331, 330, 363,
2162,   2,   2,   2,   0
 319, 309, 320, 353,
2163,   2,   2,   2,   0
 319, 320, 331, 353,
2164,   2,   2,   2,   0
 309, 321, 320, 353,
2165,   2,   2,   2,   0
 331, 320, 321, 353,
2166,   2,   2,   2,   0
 309, 310, 321, 343,
2167,   2,   2,   2,   0
 331, 321, 332, 365,
2168,   2,   2,   2,   0
 321, 310, 311, 343,
2169,   2,   2,   2,   0
 321, 333, 332, 365,
2170,   2,   2,   2,   0
 321, 311, 322, 355,
2171,   2,   2,   2,   0
 321, 322, 333, 355,
2172,   2,   2,   2,   0
 311, 323, 322, 355,
2173,   2,   2,   2,   0
 333, 322, 323, 355,
2174,   2,   2,   2,   0
 311, 312, 323, 345,
2175,   2,   2,   2,   0
 333, 323, 334, 367,
2176,   2,   2,   2,   0
 323, 312, 313, 345,
2177,   2,   2,   2,   0
 323, 335, 334, 367,
2178,   2,   2,   2,   0
 323, 313, 324, 357,
2179,   2,   2,   2,   0
 323, 324, 335, 357,
2180,   2,   2,   2,   0
 313, 325, 324, 357,
2181,   2,   2,   2,   0
 335, 324, 325, 357,
2182,   2,   2,   2,   0
 313, 314, 325, 347,
2183,   2,   2,   2,   0
 335, 325, 336, 369,
```

```
2184,   2,   2,   2,   0
 315,  337,  305,  349,
2185,   2,   2,   2,   0
 315,  327,  359,  349,
2186,   2,   2,   2,   0
 305,  317,  349,  339,
2187,   2,   2,   2,   0
 327,  349,  317,  361,
2188,   2,   2,   2,   0
 317,  339,  307,  351,
2189,   2,   2,   2,   0
 317,  329,  361,  351,
2190,   2,   2,   2,   0
 307,  319,  351,  341,
2191,   2,   2,   2,   0
 329,  351,  319,  363,
2192,   2,   2,   2,   0
 319,  341,  309,  353,
2193,   2,   2,   2,   0
 319,  331,  363,  353,
2194,   2,   2,   2,   0
 309,  321,  353,  343,
2195,   2,   2,   2,   0
 331,  353,  321,  365,
2196,   2,   2,   2,   0
 321,  343,  311,  355,
2197,   2,   2,   2,   0
 321,  333,  365,  355,
2198,   2,   2,   2,   0
 311,  323,  355,  345,
2199,   2,   2,   2,   0
 333,  355,  323,  367,
2200,   2,   2,   2,   0
 323,  345,  313,  357,
2201,   2,   2,   2,   0
 323,  335,  367,  357,
2202,   2,   2,   2,   0
 313,  325,  357,  347,
2203,   2,   2,   2,   0
 335,  357,  325,  369,
2204,   4,   1,   4,   0
 481,  244,
2205,   2,   2,   2,   0
 315,  348,  337,  349,
2206,   2,   2,   2,   0
 315,  348,  349,  359,
2207,   2,   2,   2,   0
 337,  338,  305,  349,
2208,   2,   2,   2,   0
 327,  359,  349,  360,
2209,   2,   2,   2,   0
 305,  338,  339,  349,
2210,   2,   2,   2,   0
 327,  360,  349,  361,
```

```
2211,   2,   2,   2,   0
 317,  349,  339,  350,
2212,   2,   2,   2,   0
 349,  350,  317,  361,
2213,   2,   2,   2,   0
 317,  350,  339,  351,
2214,   2,   2,   2,   0
 317,  350,  351,  361,
2215,   2,   2,   2,   0
 339,  340,  307,  351,
2216,   2,   2,   2,   0
 329,  361,  351,  362,
2217,   2,   2,   2,   0
 307,  340,  341,  351,
2218,   2,   2,   2,   0
 329,  362,  351,  363,
2219,   2,   2,   2,   0
 319,  351,  341,  352,
2220,   2,   2,   2,   0
 351,  352,  319,  363,
2221,   2,   2,   2,   0
 319,  352,  341,  353,
2222,   2,   2,   2,   0
 319,  352,  353,  363,
2223,   2,   2,   2,   0
 341,  342,  309,  353,
2224,   2,   2,   2,   0
 331,  363,  353,  364,
2225,   2,   2,   2,   0
 309,  342,  343,  353,
2226,   2,   2,   2,   0
 331,  364,  353,  365,
2227,   2,   2,   2,   0
 321,  353,  343,  354,
2228,   2,   2,   2,   0
 353,  354,  321,  365,
2229,   2,   2,   2,   0
 321,  354,  343,  355,
2230,   2,   2,   2,   0
 321,  354,  355,  365,
2231,   2,   2,   2,   0
 343,  344,  311,  355,
2232,   2,   2,   2,   0
 333,  365,  355,  366,
2233,   2,   2,   2,   0
 311,  344,  345,  355,
2234,   2,   2,   2,   0
 333,  366,  355,  367,
2235,   2,   2,   2,   0
 323,  355,  345,  356,
2236,   2,   2,   2,   0
 355,  356,  323,  367,
2237,   2,   2,   2,   0
 323,  356,  345,  357,
```

```
2238,   2,    2,    2,    0
 323,  356,  357,  367,
2239,   2,    2,    2,    0
 345.  346,  313,  357,
2240,   2,    2,    2,    0
 335,  367,  357,  368,
2241,   2,    2,    2,    0
 313,  346,  347,  357,
2242,   2,    2,    2,    0
 335,  368,  357,  369,
2243,   2,    2,    2,    0
 325,  357,  347,  358,
2244,   2,    2,    2,    0
 357.  358,  325,  369,
2245,   4,    1,    4,    0
 408.  298,
2246,   4,    1,    4,    0
 434.  292,
2247,   4,    1,    4,    0
 465.  303,
2248,   4,    1,    4,    0
 482.  279,
2249,   2,    2,    2,    0
 337.  349,  348.  381,
2250,   2,    2,    2,    0
 359.  348.  349.  381,
2251,   2,    2,    2,    0
 337.  338,  349,  371,
2252,   2,    2,    2,    0
 359.  349.  360,  393,
2253,   2,    2,    2,    0
 349,  338,  339,  371,
2254,   2.    2,    2,    0
 349.  361.  360,  393,
2255,   2,    2,    2,    0
 349,  339,  350.  383,
2256,   2,    2,    2,    0
 349.  350,  361.  383,
2257,   2,    2,    2,    0
 339.  351,  350,  383,
2258,   2,    2,    2,    0
 361,  350,  351,  383,
2259,   2,    2,    2,    0
 339,  340,  351,  373,
2260,   2,    2,    2,    0
 361.  351.  362,  395,
2261,   2,    2,    2.   0
 351.  340,  341,  373,
2262,   2,    2,    2,    0
 351,  363,  362.  395,
2263,   2,    2,    2,    0
 351.  341,  352,  385,
2264,   2,    2,    2.   0
 351.  352.  363,  385,
```

```
2265,   2,   2,   2,   0
 341, 353, 352, 385,
2266,   2,   2,   2,   0
 363, 352, 353, 385,
2267,   2,   2,   2,   0
 341, 342, 353, 375,
2268,   2,   2,   2,   0
 363, 353, 364, 397,
2269,   2,   2,   2,   0
 353, 342, 343, 375,
2270,   2,   2,   2,   0
 353, 365, 364, 397,
2271,   2,   2,   2,   0
 353, 343, 354, 387,
2272,   2,   2,   2,   0
 353, 354, 365, 387,
2273,   2,   2,   2,   0
 343, 355, 354, 387,
2274,   2,   2,   2,   0
 365, 354, 355, 387,
2275,   2,   2,   2,   0
 343, 344, 355, 377,
2276,   2,   2,   2,   0
 365, 355, 366, 399,
2277,   2,   2,   2,   0
 355, 344, 345, 377,
2278,   2,   2,   2,   0
 355, 367, 366, 399,
2279,   2,   2,   2,   0
 355, 345, 356, 389,
2280,   2,   2,   2,   0
 355, 356, 367, 389,
2281,   2,   2,   2,   0
 345, 357, 356, 389,
2282,   2,   2,   2,   0
 367, 356, 357, 389,
2283,   2,   2,   2,   0
 345, 346, 357, 379,
2284,   2,   2,   2,   0
 367, 357, 368, 401,
2285,   2,   2,   2,   0
 357, 346, 347, 379,
2286,   2,   2,   2,   0
 357, 369, 368, 401,
2287,   2,   2,   2,   0
 357, 347, 358, 391,
2288,   2,   2,   2,   0
 357, 358, 369, 391,
2289,   2,   2,   2,   0
 337, 349, 381, 371,
2290,   2,   2,   2,   0
 359, 381, 349, 393,
2291,   2,   2,   2,   0
 349, 371, 339, 383,
```

```
2292,   2,   2,   2,   0
 349, 361, 393, 383,
2293,   2,   2,   2,   0
 339, 351, 383, 373,
2294,   2,   2,   2,   0
 361, 383, 351, 395,
2295,   2,   2,   2,   0
 351, 373, 341, 385,
2296,   2,   2,   2,   0
 351, 363, 395, 385,
2297,   2,   2,   2,   0
 341, 353, 385, 375,
2298,   2,   2,   2,   0
 363, 385, 353, 397,
2299,   2,   2,   2,   0
 353, 375, 343, 387,
2300,   2,   2,   2,   0
 353, 365, 397, 387,
2301,   2,   2,   2,   0
 343, 355, 387, 377,
2302,   2,   2,   2,   0
 365, 387, 355, 399,
2303,   2,   2,   2,   0
 355, 377, 345, 389,
2304,   2,   2,   2,   0
 355, 367, 399, 389,
2305,   2,   2,   2,   0
 345, 357, 389, 379,
2306,   2,   2,   2,   0
 367, 389, 357, 401,
2307,   2,   2,   2,   0
 357, 379, 347, 391,
2308,   2,   2,   2,   0
 357, 369, 401, 391,
2309,   2,   2,   2,   0
 337, 370, 371, 381,
2310,   2,   2,   2,   0
 359, 392, 381, 393,
2311,   2,   2,   2,   0
 349, 381, 371, 382,
2312,   2,   2,   2,   0
 381, 382, 349, 393,
2313,   2,   2,   2,   0
 349, 382, 371, 383,
2314,   2,   2,   2,   0
 349, 382, 383, 393,
2315,   2,   2,   2,   0
 371, 372, 339, 383,
2316,   2,   2,   2,   0
 361, 393, 383, 394,
2317,   2,   2,   2,   0
 339, 372, 373, 383,
2318,   2,   2,   2,   0
 361, 394, 383, 395,
```

```
2319,   4,   1,   4,   0
 491,  307,
2320,   2,   2,   2,   0
 351,  383,  373,  384,
2321,   2,   2,   2,   0
 383,  384,  351,  395,
2322,   2,   2,   2,   0
 351,  384,  373,  385,
2323,   2,   2,   2,   0
 351,  384,  385,  395,
2324,   2,   2,   2,   0
 373,  374,  341,  385,
2325,   2,   2,   2,   0
 363,  395,  385,  396,
2326,   2,   2,   2,   0
 341,  374,  375,  385,
2327,   2,   2,   2.   0
 363,  396,  385,  397,
2328,   2,   2,   2.   0
 353,  385,  375,  386,
2329,   2,   2,   2,   0
 385,  386,  353,  397,
2330,   2,   2,   2,   0
 353,  386,  375,  387,
2331,   2,   2,   2,   0
 353,  386,  387,  397,
2332,   2,   2,   2,   0
 375,  376,  343,  387,
2333,   2,   2,   2,   0
 365,  397,  387,  398,
2334,   2,   2,   2,   0
 343,  376,  377,  387,
2335,   2,   2,   2,   0
 365,  398,  387,  399,
2336,   2,   2,   2,   0
 355,  387,  377,  388,
2337,   2,   2,   2,   0
 387,  388,  355,  399,
2338,   2,   2,   2,   0
 355,  388,  377,  389,
2339,   2,   2,   2,   0
 355,  388,  389,  399,
2340,   2,   2,   2,   0
 377,  378,  345,  389,
2341,   2,   2,   2,   0
 367,  399,  389,  400,
2342,   2,   2,   2,   0
 345,  378,  379,  389,
2343,   2,   2,   2,   0
 367,  400,  389,  401,
2344,   2,   2,   2,   0
 357,  389,  379,  390,
2345,   2,   2,   2,   0
 389,  390,  357,  401,
```

```
2346,   2,   2,   2,   0
 357, 390, 379, 391,
2347,   2,   2,   2,   0
 357, 390, 391, 401,
2348,   2,   2,   2,   0
 379, 380, 347, 391,
2349,   2,   2,   2,   0
 369, 401, 391, 402,
2350,   2,   2,   2,   0
 381, 370, 371, 403,
2351,   2,   2,   2,   0
 381, 393, 392, 425,
2352,   2,   2,   2,   0
 381, 371, 382, 415,
2353,   2,   2,   2,   0
 381, 382, 393, 415,
2354,   2,   2,   2,   0
 371, 383, 382, 415,
2355,   2,   2,   2,   0
 393, 382, 383, 415,
2356,   2,   2,   2,   0
 371, 372, 383, 405,
2357,   2,   2,   2,   0
 393, 383, 394, 427,
2358,   2,   2,   2,   0
 383, 372, 373, 405,
2359,   2,   2,   2,   0
 383, 395, 394, 427,
2360,   2,   2,   2,   0
 383, 373, 384, 417,
2361,   2,   2,   2,   0
 383, 384, 395, 417,
2362,   2,   2,   2,   0
 373, 385, 384, 417,
2363,   2,   2,   2,   0
 395, 384, 385, 417,
2364,   2,   2,   2,   0
 373, 374, 385, 407,
2365,   2,   2,   2,   0
 395, 385, 396, 429,
2366,   2,   2,   2,   0
 385, 374, 375, 407,
2367,   2,   2,   2,   0
 385, 397, 396, 429,
2368,   2,   2,   2,   0
 385, 375, 386, 419,
2369,   2,   2,   2,   0
 385, 386, 397, 419,
2370,   2,   2,   2,   0
 375, 387, 386, 419,
2371,   2,   2,   2,   0
 397, 386, 387, 419,
2372,   2,   2,   2,   0
 375, 376, 387, 409,
```

```
2373,  2,  2,  2,  0
 397, 387, 398, 431,
2374,  2,  2,  2,  0
 387, 376, 377, 409,
2375,  2,  2,  2,  0
 387, 399, 398, 431,
2376,  2,  2,  2,  0
 387, 377, 388, 421,
2377,  2,  2,  2,  0
 387, 388, 399, 421,
2378,  2,  2,  2,  0
 377, 389, 388, 421,
2379,  2,  2,  2,  0
 399, 388, 389, 421,
2380,  2,  2,  2,  0
 377, 378, 389, 411,
2381,  2,  2,  2,  0
 399, 389, 400, 433,
2382,  2,  2,  2,  0
 389, 378, 379, 411,
2383,  2,  2,  2,  0
 389, 401, 400, 433,
2384,  2,  2,  2,  0
 389, 379, 390, 423,
2385,  2,  2,  2,  0
 389, 390, 401, 423,
2386,  2,  2,  2,  0
 379, 391, 390, 423,
2387,  2,  2,  2,  0
 401, 390, 391, 423,
2388,  2,  2,  2,  0
 379, 380, 391, 413,
2389,  2,  2,  2,  0
 401, 391, 402, 435,
2390,  2,  2,  2,  0
 381, 403, 371, 415,
2391,  2,  2,  2,  0
 381, 393, 425, 415,
2392,  2,  2,  2,  0
 371, 383, 415, 405,
2393,  2,  2,  2,  0
 393, 415, 383, 427,
2394,  2,  2,  2,  0
 383, 405, 373, 417,
2395,  2,  2,  2,  0
 383, 395, 427, 417,
2396,  2,  2,  2,  0
 373, 385, 417, 407,
2397,  2,  2,  2,  0
 395, 417, 385, 429,
2398,  2,  2,  2,  0
 385, 407, 375, 419,
2399,  2,  2,  2,  0
 385, 397, 429, 419,
```

```
2400,   2,   2,   2,   0
 375,  387,  419,  409,
2401,   2,   2,   2,   0
 397,  419,  387,  431,
2402,   2,   2,   2,   0
 387,  409,  377,  421,
2403,   2,   2,   2,   0
 387,  399,  431,  421,
2404,   2,   2,   2,   0
 377,  389,  421,  411,
2405,   2,   2,   2,   0
 399,  421,  389,  433,
2406,   2,   2,   2,   0
 389,  411,  379,  423,
2407,   2,   2,   2,   0
 389,  401,  433,  423,
2408,   2,   2,   2,   0
 379,  391,  423,  413,
2409,   2,   2,   2,   0
 401,  423,  391,  435,
2410,   2,   2,   2,   0
 381,  414,  403,  415,
2411,   2,   2,   2,   0
 381,  414,  415,  425,
2412,   2,   2,   2,   0
 403,  404,  371,  415,
2413,   2,   2,   2,   0
 393,  425,  415,  426,
2414,   2,   2,   2,   0
 371,  404,  405,  415,
2415,   2,   2,   2,   0
 393,  426,  415,  427,
2416,   2,   2,   2,   0
 383,  415,  405,  416,
2417,   2,   2,   2,   0
 415,  416,  383,  427,
2418,   2,   2,   2,   0
 383,  416,  405,  417,
2419,   2,   2,   2,   0
 383,  416,  417,  427,
2420,   2,   2,   2,   0
 405,  406,  373,  417,
2421,   2,   2,   2,   0
 395,  427,  417,  428,
2422,   2,   2,   2,   0
 373,  406,  407,  417,
2423,   2,   2,   2,   0
 395,  428,  417,  429,
2424,   2,   2,   2,   0
 385,  417,  407,  418,
2425,   2,   2,   2,   0
 417,  418,  385,  429,
2426,   2,   2,   2,   0
 385,  418,  407,  419,
```

```
2427,   2,   2,   2,   0
 385,  418,  419,  429,
2428,   2,   2,   2,   0
 407,  408,  375,  419,
2429,   2,   2,   2,   0
 397,  429,  419,  430,
2430,   2,   2,   2,   0
 375,  408,  409,  419,
2431,   2,   2,   2,   0
 397,  430,  419,  431,
2432,   2,   2,   2,   0
 387,  419,  409,  420,
2433,   2,   2,   2,   0
 419,  420,  387,  431,
2434,   2,   2,   2,   0
 387,  420,  409,  421,
2435,   2,   2,   2,   0
 387,  420,  421,  431,
2436,   2,   2,   2,   0
 409,  410,  377,  421,
2437,   2,   2,   2.   0
 399,  431,  421,  432,
2438,   2,   2,   2,   0
 377,  410,  411,  421,
2439,   2,   2,   2,   0
 399,  432,  421,  433,
2440,   2,   2,   2,   0
 389,  421,  411,  422,
2441,   2,   2,   2.   0
 421,  422,  389,  433,
2442,   2,   2,   2,   0
 389,  422,  411,  423,
2443,   2,   2,   2,   0
 389,  422,  423,  433,
2444,   2,   2,   2,   0
 411,  412,  379,  423,
2445,   2,   2,   2.   0
 401,  433,  423,  434,
2446,   2,   2,   2,   0
 379,  412,  413,  423,
2447,   2,   2,   2,   0
 401,  434,  423,  435,
2448,   2,   2,   2,   0
 391,  423,  413,  424,
2449,   2,   2,   2,   0
 423,  424,  391,  435,
2450,   5,   3,   5,   0
 403,  425,
2451,   5,   3,   5,   0
 413,  403,
2452,   5,   3,   5,   0
 425,  435,
2453,   5,   3,   5,   0
 435,  413,
```

```
2454,   5,   3,   5,   0
 403,  436,
2455,   5,   3,   5,   0
 425,  442,
2456,   5,   3,   5,   0
 413,  441,
2457,   5,   3,   5,   0
 447,  435,
2458,   5,   3,   5,   0
 442,  436,
2459,   5,   3,   5,   0
 436,  441,
2460,   5,   3,   5,   0
 447,  442,
2461,   5,   3,   5,   0
 441,  447,
2462,   3,   2,   3,   0
 442,  436,  437,  448,
2463,   3,   2,   3,   0
 442,  437,  443,  455,
2464,   3,   2,   3,   0
 437,  444,  443,  455,
2465,   3,   2,   3,   0
 437,  438,  444,  450,
2466,   3,   2,   3,   0
 444,  438,  439,  450,
2467,   3,   2,   3,   0
 444,  439,  445,  457,
2468,   3,   2,   3,   0
 439,  446,  445,  457,
2469,   3,   2,   3,   0
 439,  440,  446,  452,
2470,   3,   2,   3,   0
 446,  440,  441,  452,
2471,   3,   2,   3,   0
 446,  441,  447,  459,
2472,   3,   2,   3,   0
 442,  448,  437,  455,
2473,   3,   2,   3,   0
 437,  444,  455,  450,
2474,   3,   2,   3,   0
 444,  450,  439,  457,
2475,   3,   2,   3,   0
 439,  446,  457,  452,
2476,   3,   2,   3,   0
 446,  452,  441,  459,
2477,   3,   2,   3,   0
 442,  454,  448,  455,
2478,   3,   2,   3,   0
 448,  449,  437,  455,
2479,   3,   2,   3,   0
 437,  449,  450,  455,
2480,   3,   2,   3,   0
 444,  455,  450,  456,
```

```
2481,  3,  2,  3,  0
 444, 456, 450, 457,
2482,  3,  2,  3,  0
 450, 451, 439, 457,
2483,  3,  2,  3,  0
 439, 451, 452, 457,
2484,  3,  2,  3,  0
 446, 457, 452, 458,
2485,  3,  2,  3,  0
 446, 458, 452, 459,
2486,  3,  2,  3,  0
 452, 453, 441, 459,
2487,  3,  2,  3,  0
 448, 455, 454, 466,
2488,  3,  2,  3,  0
 448, 449, 455, 461,
2489,  3,  2,  3,  0
 455, 449, 450, 461,
2490,  3,  2,  3,  0
 455, 450, 456, 468,
2491,  3,  2,  3,  0
 450, 457, 456, 468,
2492,  3,  2,  3,  0
 450, 451, 457, 463,
2493,  3,  2,  3,  0
 457, 451, 452, 463,
2494,  3,  2,  3,  0
 457, 452, 458, 470,
2495,  3,  2,  3,  0
 452, 459, 458, 470,
2496,  3,  2,  3,  0
 452, 453, 459, 465,
2497,  3,  2,  3,  0
 448, 455, 466, 461,
2498,  3,  2,  3,  0
 455, 461, 450, 468,
2499,  3,  2,  3,  0
 450, 457, 468, 463,
2500,  3,  2,  3,  0
 457, 463, 452, 470,
2501,  3,  2,  3,  0
 452, 459, 470, 465,
2502,  3,  2,  3,  0
 448, 460, 461, 466,
2503,  3,  2,  3,  0
 455, 466, 461, 467,
2504,  3,  2,  3,  0
 455, 467, 461, 468,
2505,  3,  2,  3,  0
 461, 462, 450, 468,
2506,  3,  2,  3,  0
 450, 462, 463, 468,
2507,  3,  2,  3,  0
 457, 468, 463, 469,
```

```
2508,   3,   2,   3,   0
 457,  469,  463,  470,
2509,   3,   2,   3,   0
 463,  464,  452,  470,
2510,   3,   2,   3,   0
 452,  464,  465,  470,
2511,   3,   2,   3,   0
 459,  470,  465,  471,
2512,   3,   2,   3,   0
 466,  460,  461,  472,
2513,   3,   2,   3,   0
 466,  461,  467,  479,
2514,   3,   2,   3,   0
 461,  468,  467,  479,
2515,   3,   2,   3,   0
 461,  462,  468,  474,
2516,   3,   2,   3,   0
 468,  462,  463,  474,
2517,   3,   2,   3,   0
 468,  463,  469,  481,
2518,   3,   2,   3,   0
 463,  470,  469,  481,
2519,   3,   2,   3,   0
 463,  464,  470,  476,
2520,   3,   2,   3,   0
 470,  464,  465,  476,
2521,   3,   2,   3,   0
 470,  465,  471,  483,
2522,   3,   2,   3,   0
 466,  472,  461,  479,
2523,   3,   2,   3,   0
 461,  468,  479,  474,
2524,   3,   2,   3,   0
 468,  474,  463,  481,
2525,   3,   2,   3,   0
 463,  470,  481,  476,
2526,   3,   2,   3,   0
 470,  476,  465,  483,
2527,   3,   2,   3,   0
 466,  478,  472,  479,
2528,   3,   2,   3,   0
 472,  473,  461,  479,
2529,   3,   2,   3,   0
 461,  473,  474,  479,
2530,   3,   2,   3,   0
 468,  479,  474,  480,
2531,   3,   2,   3,   0
 468,  480,  474,  481,
2532,   3,   2,   3,   0
 474,  475,  463,  481,
2533,   3,   2,   3,   0
 463,  475,  476,  481,
2534,   3,   2,   3,   0
 470,  481,  476,  482,
```

```
2535,   3,    2,    3,   0
 470,  482,  476,  483,
2536,   3,    2,    3,   0
 476,  477,  465,  483,
2537,   3,    2,    3,   0
 472,  479,  478,  490,
2538,   3,    2,    3,   0
 472,  473,  479,  485,
2539,   3,    2,    3,   0
 479,  473,  474,  485,
2540,   3,    2,    3,   0
 479,  474,  480,  492,
2541,   3,    2,    3,   0
 474,  481,  480,  492,
2542,   3,    2,    3,   0
 474,  475,  481,  487,
2543,   3,    2,    3,   0
 481,  475,  476,  487,
2544,   3,    2,    3,   0
 481,  476,  482,  494,
2545,   3,    2,    3,   0
 476,  483,  482,  494,
2546,   3,    2,    3,   0
 476,  477,  483,  489,
2547,   3,    2,    3,   0
 472,  479,  490,  485,
2548,   3,    2,    3,   0
 479,  485,  474,  492,
2549,   3,    2,    3,   0
 474,  481,  492,  487,
2550,   3,    2,    3,   0
 481,  487,  476,  494,
2551,   3,    2,    3,   0
 476,  483,  494,  489,
2552,   3,    2,    3,   0
 472,  484,  485,  490,
2553,   3,    2,    3,   0
 479,  490,  485,  491,
2554,   3,    2,    3,   0
 479,  491,  485,  492,
2555,   3,    2,    3,   0
 485,  486,  474,  492,
2556,   3,    2,    3,   0
 474,  486,  487,  492,
2557,   3,    2,    3,   0
 481,  492,  487,  493,
2558,   3,    2,    3,   0
 481,  493,  487,  494,
2559,   3,    2,    3,   0
 487,  488,  476,  494,
2560,   3,    2,    3,   0
 476,  488,  489,  494,
2561,   3,    2,    3,   0
 483,  494,  489,  495,
```

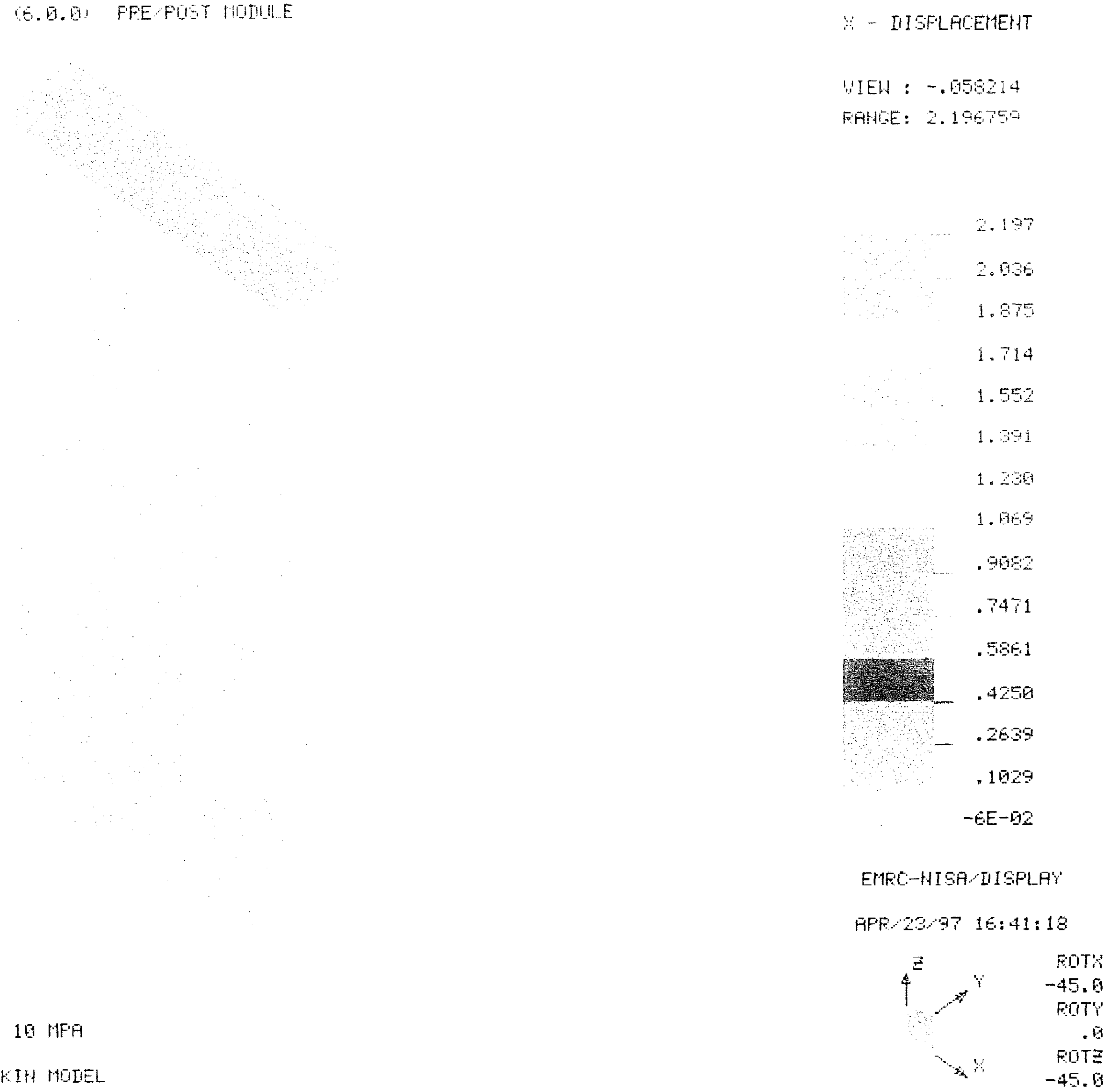
```
2562,   3,   2,   3,   0
 490,  484,  485,  496,
2563,   3,   2,   3,   0
 490,  485,  491,  503,
2564,   3,   2,   3,   0
 485,  492,  491,  503,
2565,   3,   2,   3,   0
 485,  486,  492,  498,
2566,   3,   2,   3,   0
 492,  486,  487,  498,
2567,   3,   2,   3,   0
 492,  487,  493,  505,
2568,   3,   2,   3,   0
 487,  494,  493,  505,
2569,   3,   2,   3,   0
 487,  488,  494,  500,
2570,   3,   2,   3,   0
 494,  488,  489,  500,
2571,   3,   2,   3,   0
 494,  489,  495,  507,
2572,   3,   2,   3,   0
 490,  496,  485,  503,
2573,   3,   2,   3,   0
 485,  492,  503,  498,
2574,   3,   2,   3,   0
 492,  498,  487,  505,
2575,   3,   2,   3,   0
 487,  494,  505,  500,
2576,   3,   2,   3,   0
 494,  500,  489,  507,
2577,   3,   2,   3,   0
 490,  502,  496,  503,
2578,   3,   2,   3,   0
 496,  497,  485,  503,
2579,   3,   2,   3,   0
 485,  497,  498,  503,
2580,   3,   2,   3,   0
 492,  503,  498,  504,
2581,   3,   2,   3,   0
 492,  504,  498,  505,
2582,   3,   2,   3,   0
 498,  499,  487,  505,
2583,   3,   2,   3,   0
 487,  499,  500,  505,
2584,   3,   2,   3,   0
 494,  505,  500,  506,
2585,   3,   2,   3,   0
 494,  506,  500,  507,
2586,   3,   2,   3,   0
 500,  501,  489,  507,
*MATERIAL
EX  ,    1,0, 5.00000E+01,
EY  ,    1,0, 5.00000E+01,
EZ  ,    1,0, 5.00000E+01,
```

```
NUXY,    1,0, 2.00000E-01,
NUXZ,    1,0, 2.00000E-01,
NUYZ,    1,0, 2.00000E-01,
DENS,    1,0, 5.50000E-06,
EX  ,    2,0, 1.00000E+02,
EY  ,    2,0, 1.00000E+02,
EZ  ,    2,0, 1.00000E+02,
NUXY,    2,0, 2.00000E-01,
NUXZ,    2,0, 2.00000E-01,
NUYZ,    2,0, 2.00000E-01,
DENS,    2,0, 8.00000E-06,
EX  ,    3,0, 1.00000E+03,
EY  ,    3,0, 1.00000E+03,
EZ  ,    3,0, 1.00000E+03,
NUXY,    3,0, 2.00000E-01,
NUXZ,    3,0, 2.00000E-01,
NUYZ,    3,0, 2.00000E-01,
DENS,    3,0, 1.05600E-05,
EX  ,    4,0, 1.00000E+03,
EY  ,    4,0, 1.00000E+03,
EZ  ,    4,0, 1.00000E+03,
NUXY,    4,0, 2.00000E-01,
NUXZ,    4,0, 2.00000E-01,
NUYZ,    4,0, 2.00000E-01,
DENS,    4,0, 1.80000E-05,
NUXY,    5,0, 2.00000E-01,
*TIMEAMP
333,1,0
1.0,1.0
*EVENT, ID = 1
INCREMENTS = EQUAL,10
TIMEATEND = 1.0
MAXITERATIONS = 10
TOLERANCES = .1E-03,.1E-03,.1E-03
*SPDISP
** SPDISP SET =     1
   1,UX  , 0.00000E+00,,,,,,,,    0
   1,UY  , 0.00000E+00,,,,,,,,    0
   1,UZ  , 0.00000E+00,,,,,,,,    0
   6,UX  , 0.00000E+00,,,,,,,,    0
   6,UY  , 0.00000E+00,,,,,,,,    0
   6,UZ  , 0.00000E+00,,,,,,,,    0
   7,UX  , 0.00000E+00,,,,,,,,    0
   7,UY  , 0.00000E+00,,,,,,,,    0
   7,UZ  , 0.00000E+00,,,,,,,,    0
  12,UX  , 0.00000E+00,,,,,,,,    0
  12,UY  , 0.00000E+00,,,,,,,,    0
  12,UZ  , 0.00000E+00,,,,,,,,    0
*PRESSURE, TCRV = 333
** PRESSURE SET =     1
 2581,,,3,0,  0, .100E+02,    0
*NLOUT
1,3,0,1,0,1,0,0
*ENDDATA
```

APPENDIX B

RESULTS OF THE ANALYSIS AT 10 MPa

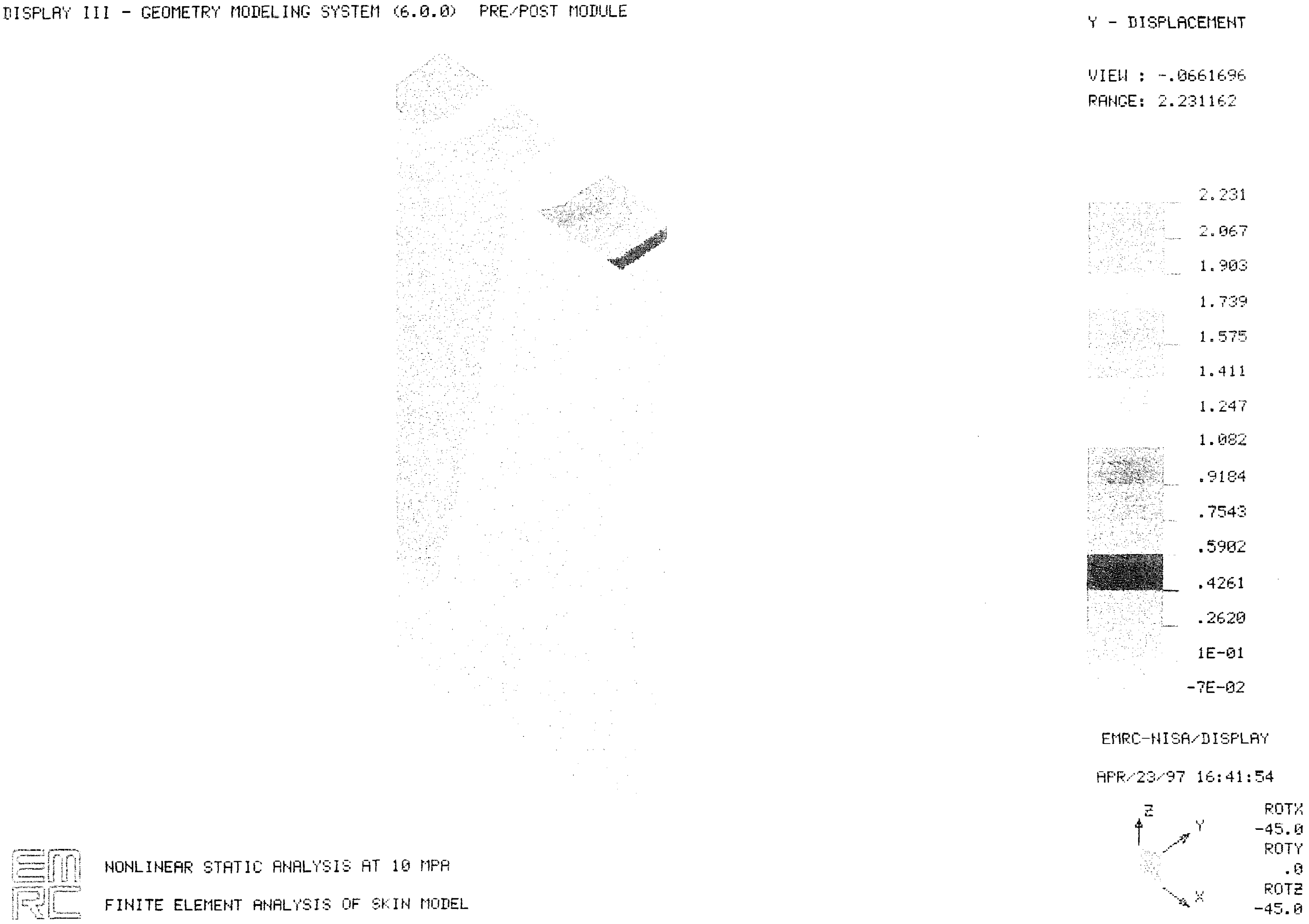
DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE



EMRC

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL



DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

Y - DISPLACEMENT

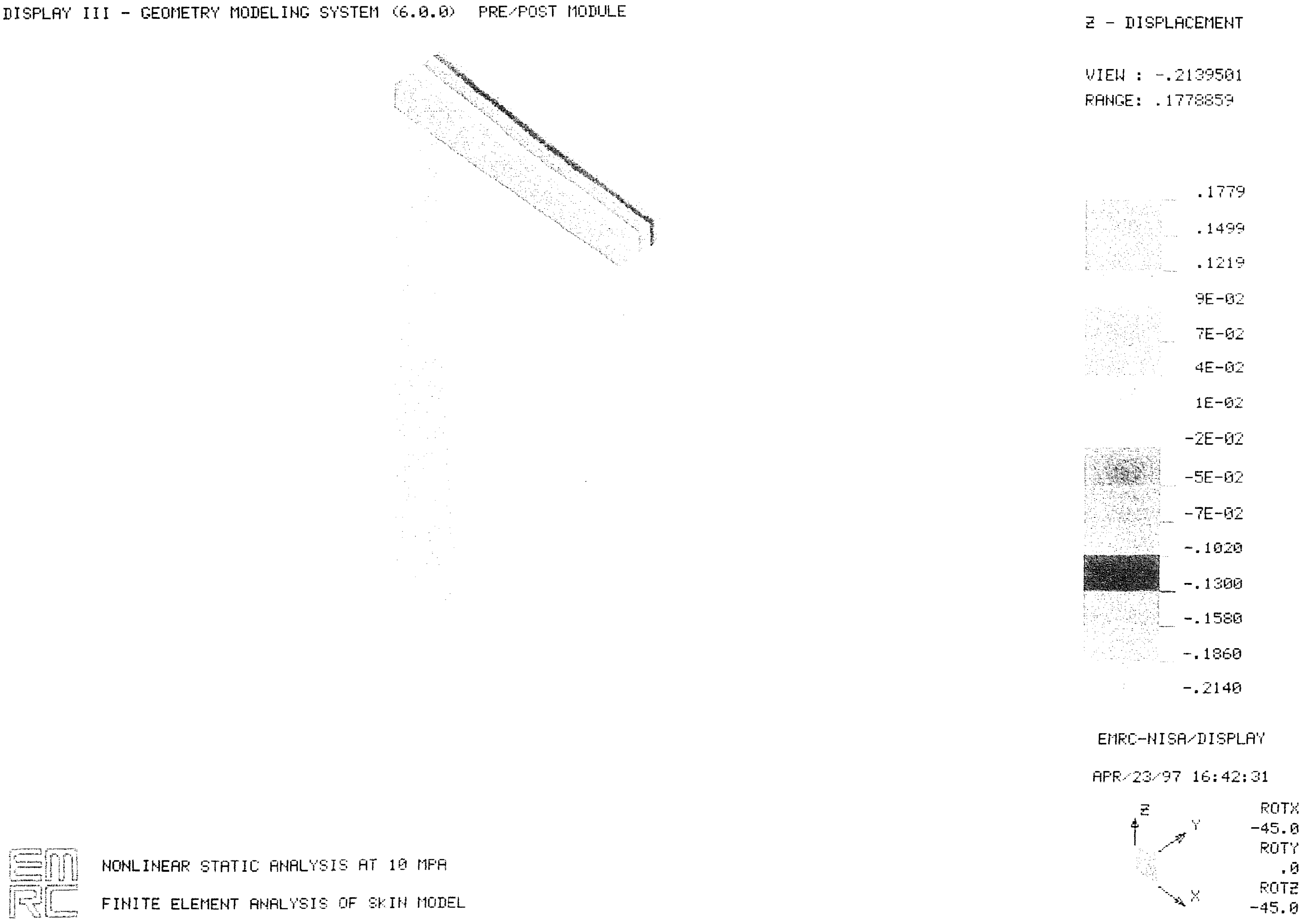
VIEW : -.0661696
RANGE: 2.231162

EMRC-NISA/DISPLAY

APR/23/97 16:41:54

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL


DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

Z - DISPLACEMENT

VIEW : -.2139501
RANGE: .1778859

EMRC-NISA/DISPLAY

APR/23/97 16:42:31

ROTX -45.0
ROTY .0
ROTZ -45.0

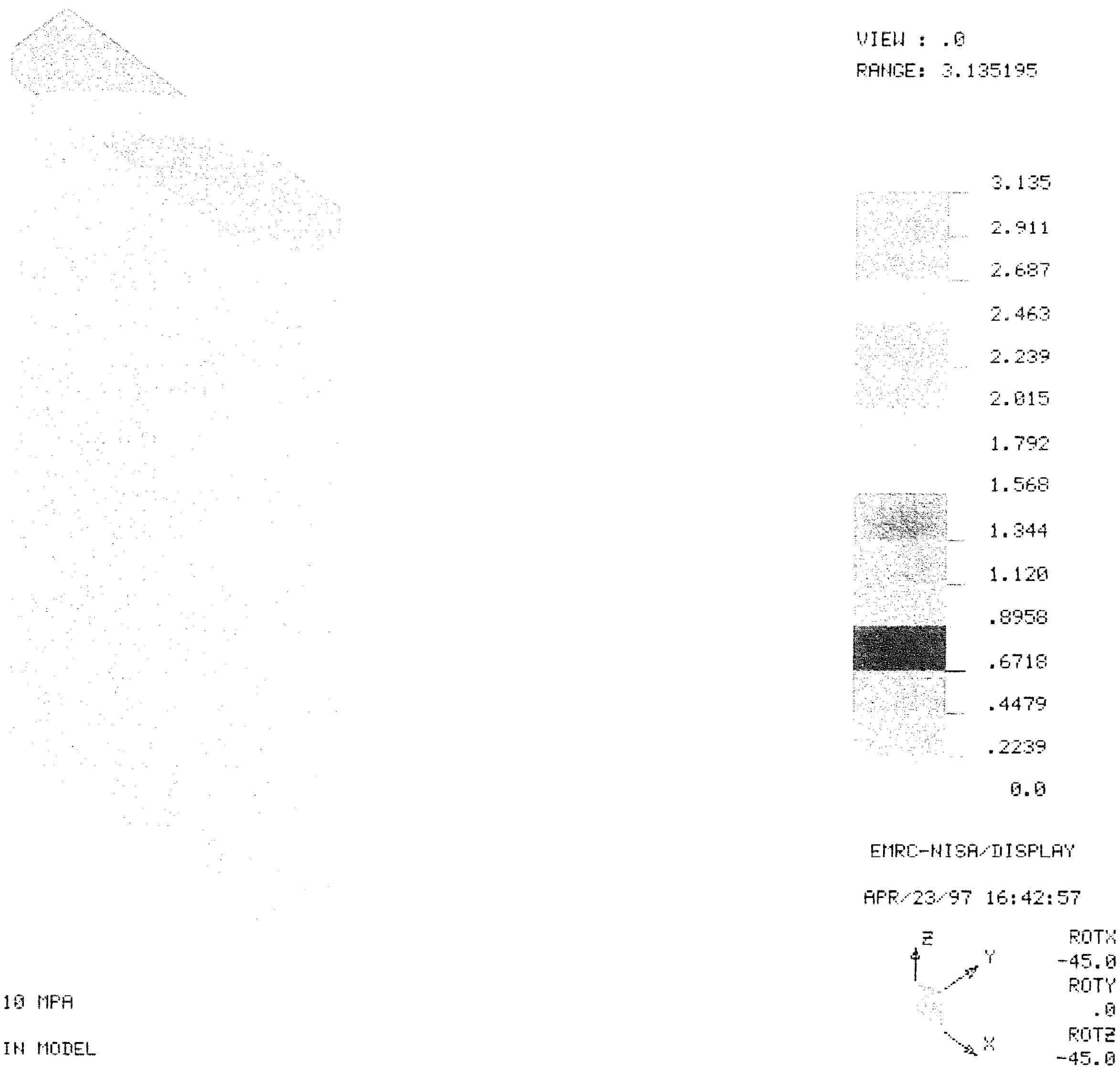
NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL

DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0)   PRE/POST MODULE

RESULTANT DISPL.

VIEW : .0
RANGE: 3.135195

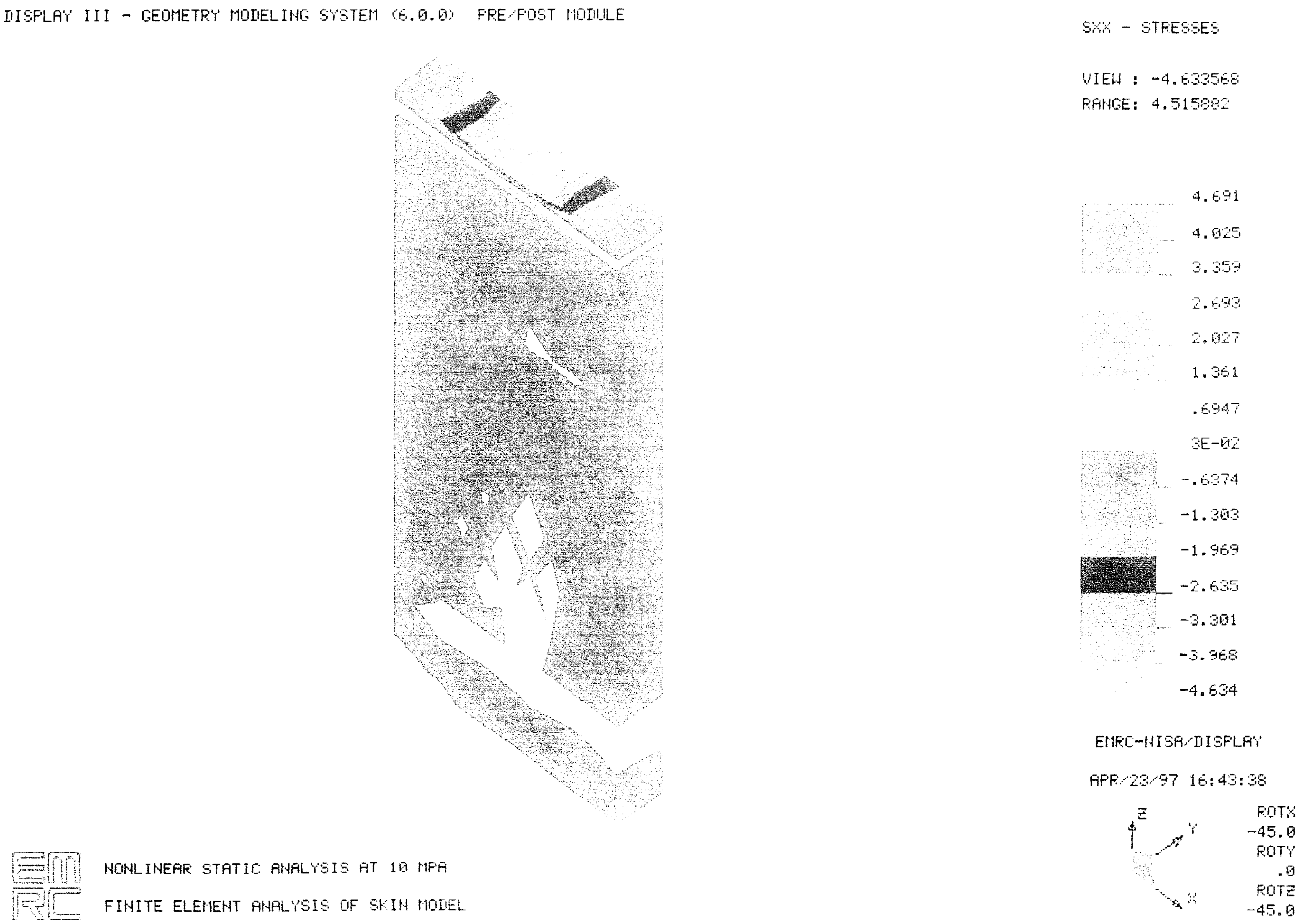


EMRC-NISA/DISPLAY

APR/23/97 16:42:57

NONLINEAR STATIC ANALYSIS AT 10 MPA

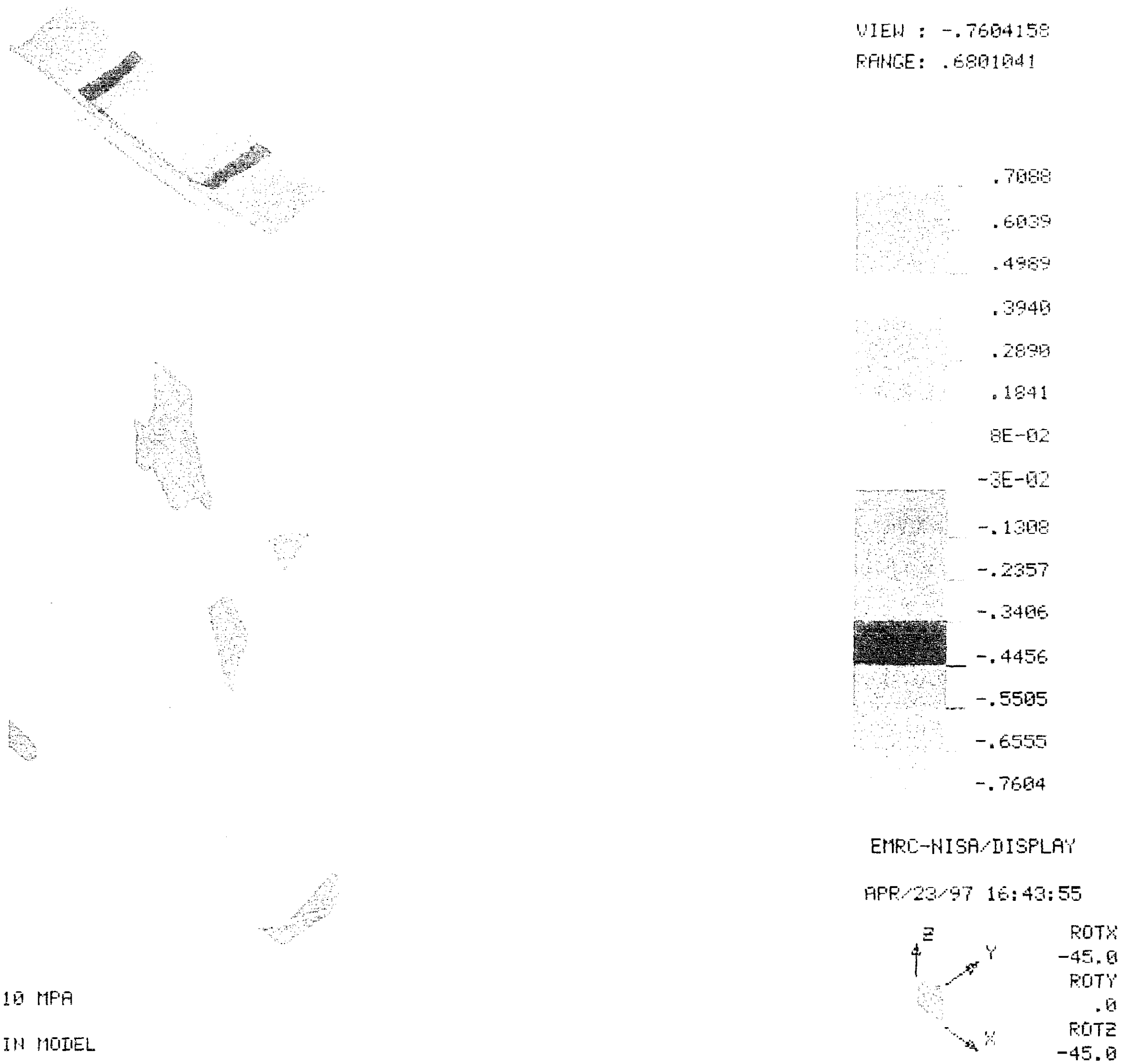
FINITE ELEMENT ANALYSIS OF SKIN MODEL


DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE
SXX - STRESSES
VIEW : -4.633568
RANGE: 4.515882
4.691
4.025
3.359
2.693
2.027
1.361
.6947
3E-02
-.6374
-1.303
-1.969
-2.635
-3.301
-3.968
-4.634
EMRC-NISA/DISPLAY
APR/23/97 16:43:38
Z
Y
X
ROTX
-45.0
ROTY
.0
ROTZ
-45.0
EMRC
NONLINEAR STATIC ANALYSIS AT 10 MPA
FINITE ELEMENT ANALYSIS OF SKIN MODEL

DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0)   PRE/POST MODULE

SYY - STRESSES

VIEW : -.7604158
RANGE: .6801041

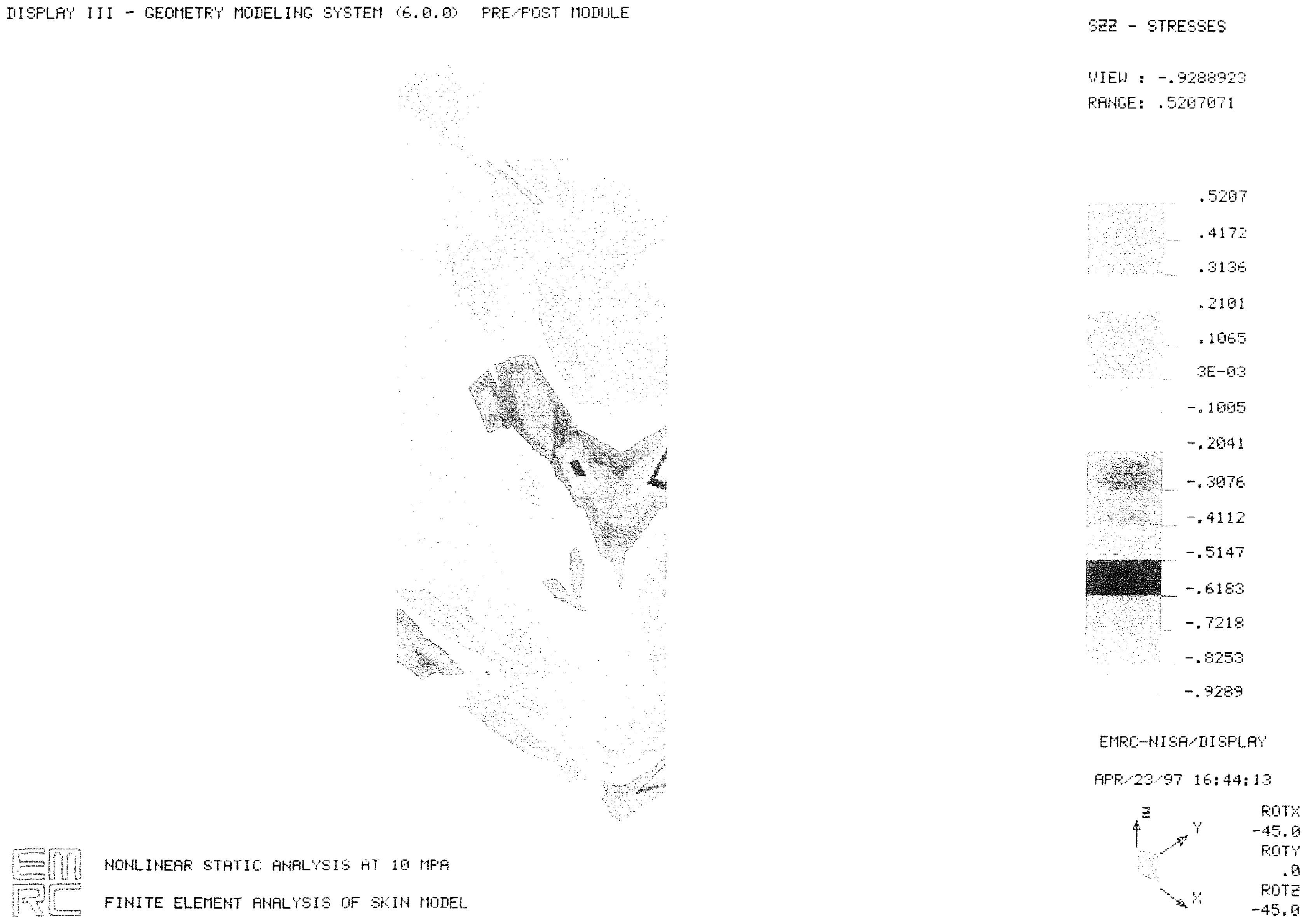


EMRC-NISA/DISPLAY

APR/23/97 16:43:55

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL



DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

SZZ - STRESSES

VIEW : -.9288923
RANGE: .5207071

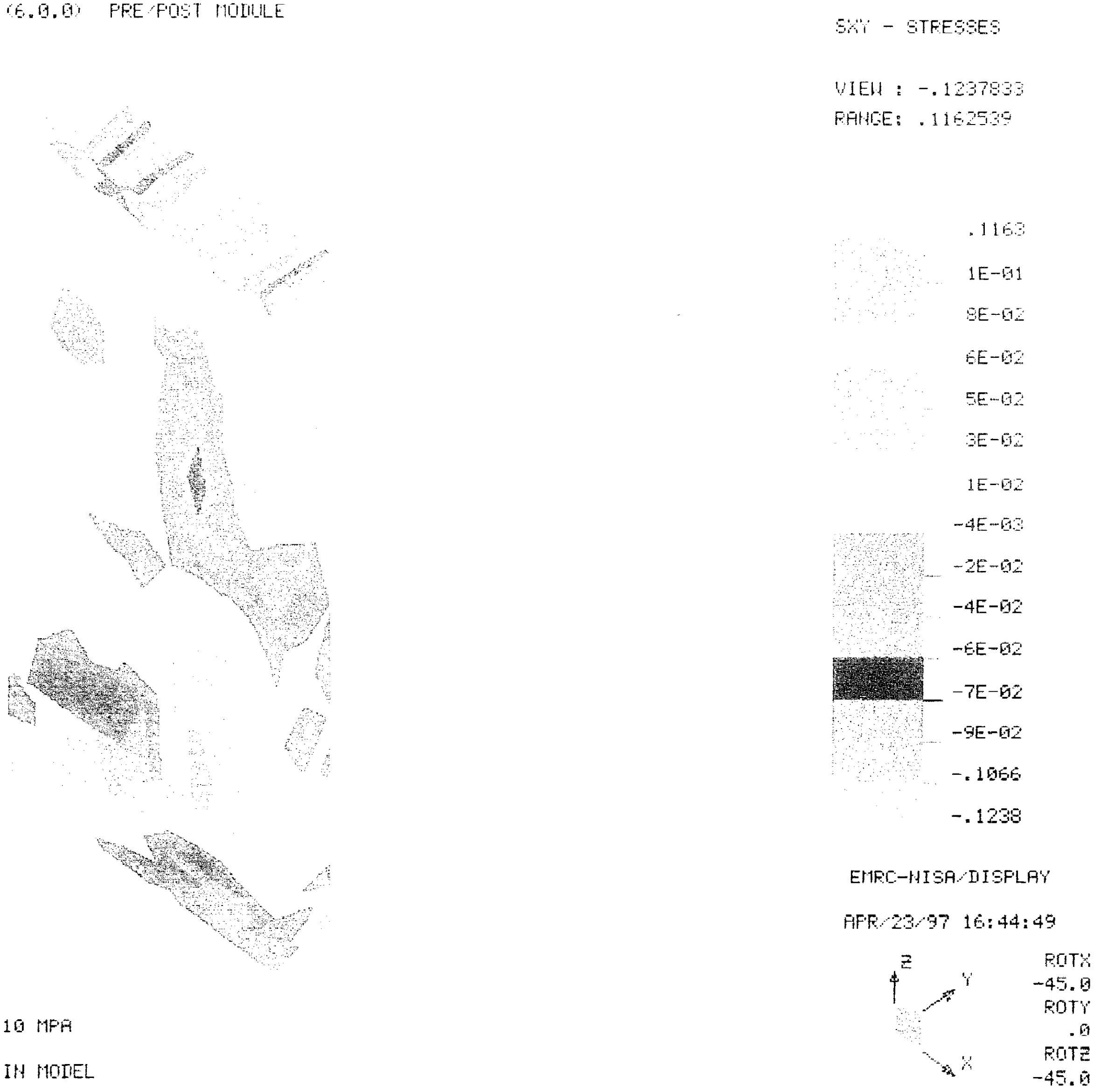
EMRC-NISA/DISPLAY

APR/23/97 16:44:13

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL

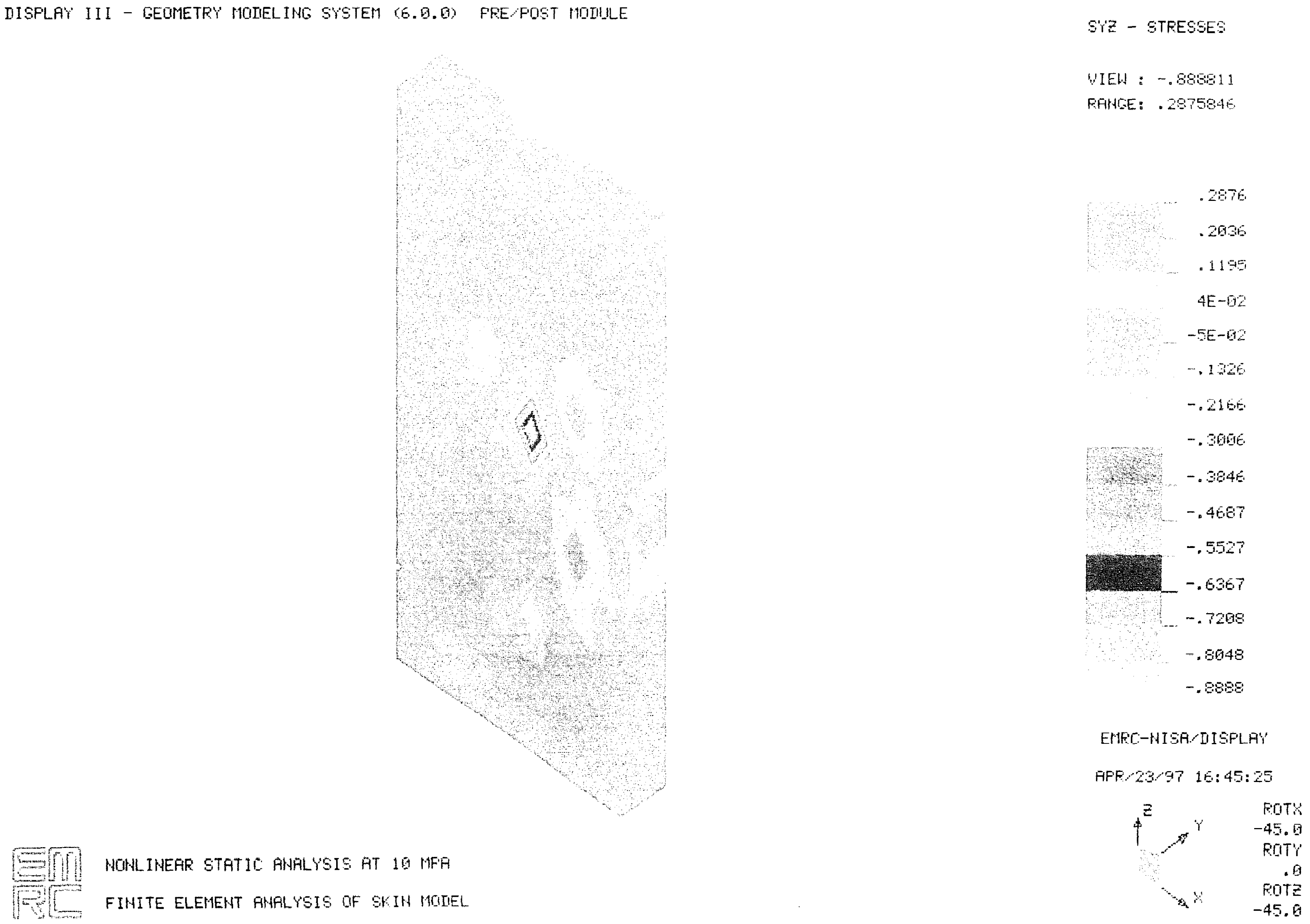
DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0)   PRE/POST MODULE

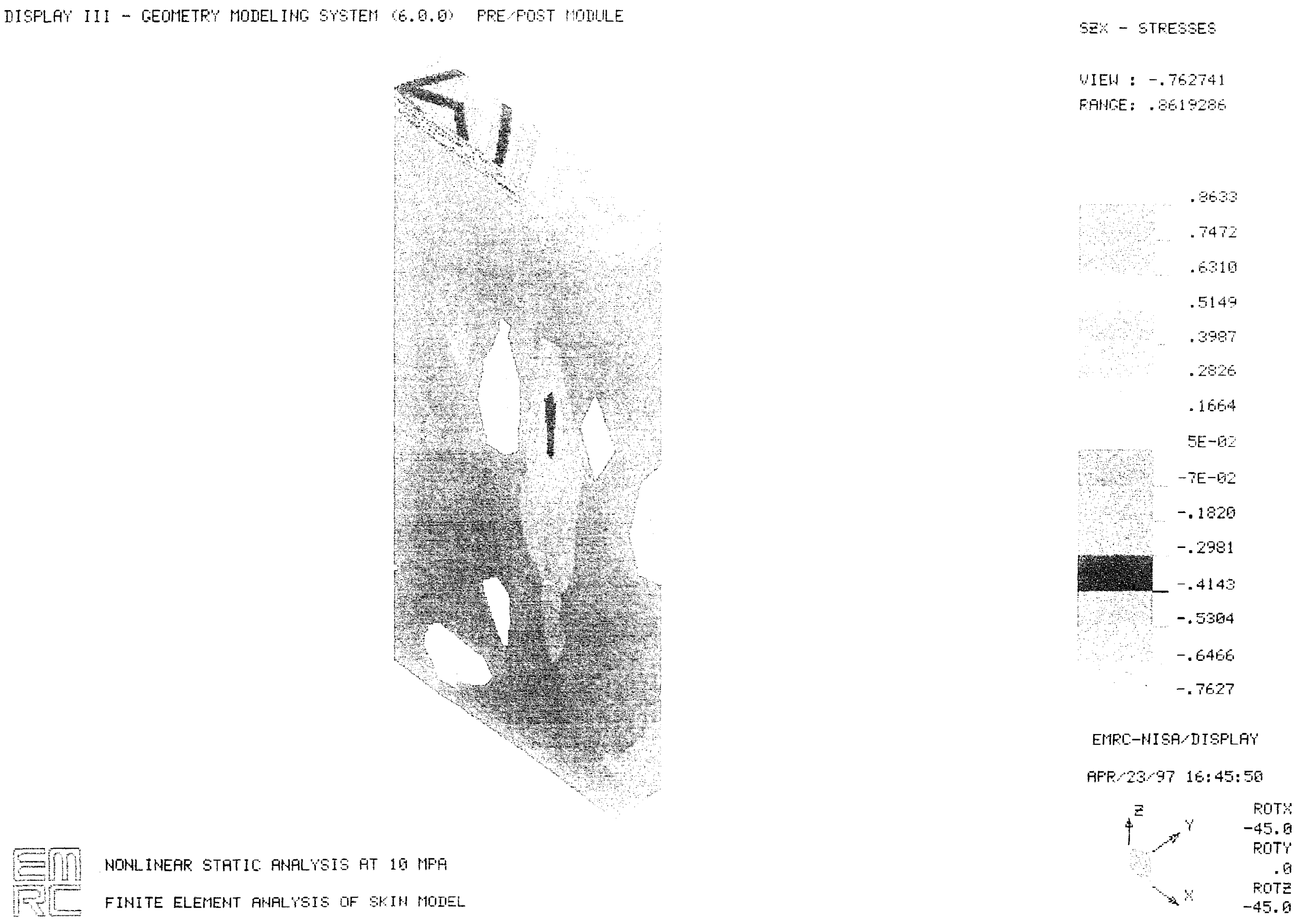


EMRC

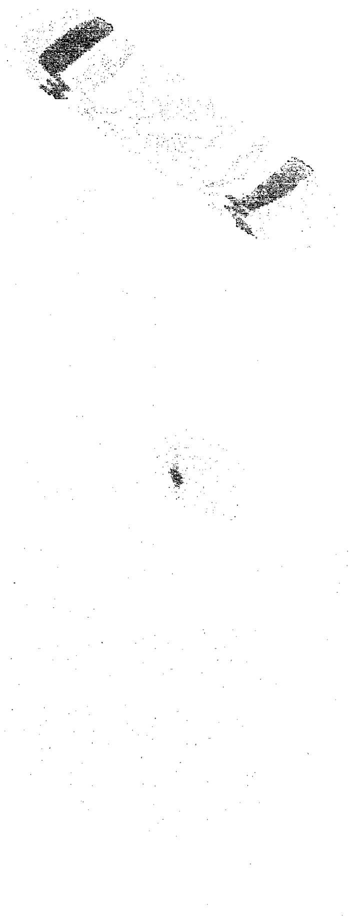
NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL


DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE
SYZ - STRESSES
VIEW : -.888811
RANGE: .2875846
.2876
.2036
.1195
4E-02
-5E-02
-.1326
-.2166
-.3006
-.3846
-.4687
-.5527
-.6367
-.7208
-.8048
-.8888
EMRC-NISA/DISPLAY
APR/23/97 16:45:25
Z
Y
X
ROTX
-45.0
ROTY
.0
ROTZ
-45.0
EMRC
NONLINEAR STATIC ANALYSIS AT 10 MPA
FINITE ELEMENT ANALYSIS OF SKIN MODEL


DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE
SEX - STRESSES
VIEW : -.762741
RANGE: .8619286
.8633
.7472
.6310
.5149
.3987
.2826
.1664
5E-02
-7E-02
-.1820
-.2981
-.4143
-.5304
-.6466
-.7627
EMRC-NISA/DISPLAY
APR/23/97 16:45:50
Z
Y
X
ROTX
-45.0
ROTY
.0
ROTZ
-45.0
NONLINEAR STATIC ANALYSIS AT 10 MPA
FINITE ELEMENT ANALYSIS OF SKIN MODEL

DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE



EFFECTIVE STRESS

VIEW : .0050219
RANGE: 9.491547

9.504
8.826
8.147
7.469
6.790
6.112
5.433
4.755
4.076
3.398
2.719
2.041
1.362
.6835
5E-03

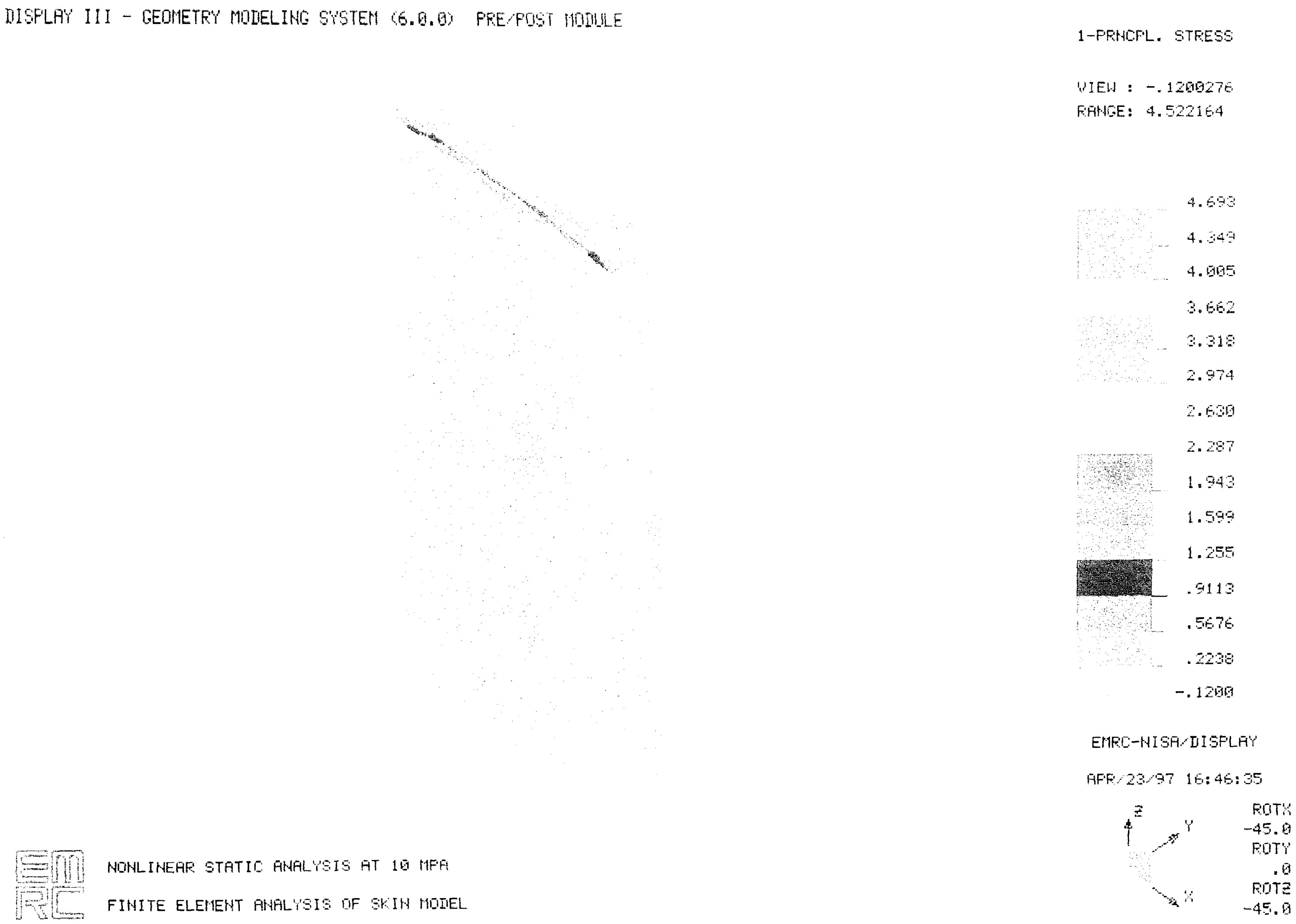
EMRC-NISA/DISPLAY

APR/23/97 16:46:12

ROTX
-45.0
ROTY
.0
ROTZ
-45.0

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL



DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

1-PRNCPL. STRESS

VIEW : -.1200276
RANGE: 4.522164

EMRC-NISA/DISPLAY

APR/23/97 16:46:35

ROTX
-45.0
ROTY
.0
ROTZ
-45.0

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL

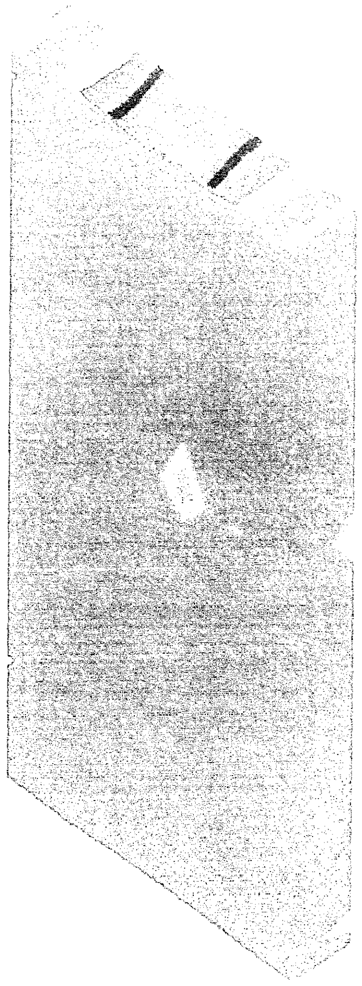
DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE

EMRC

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL

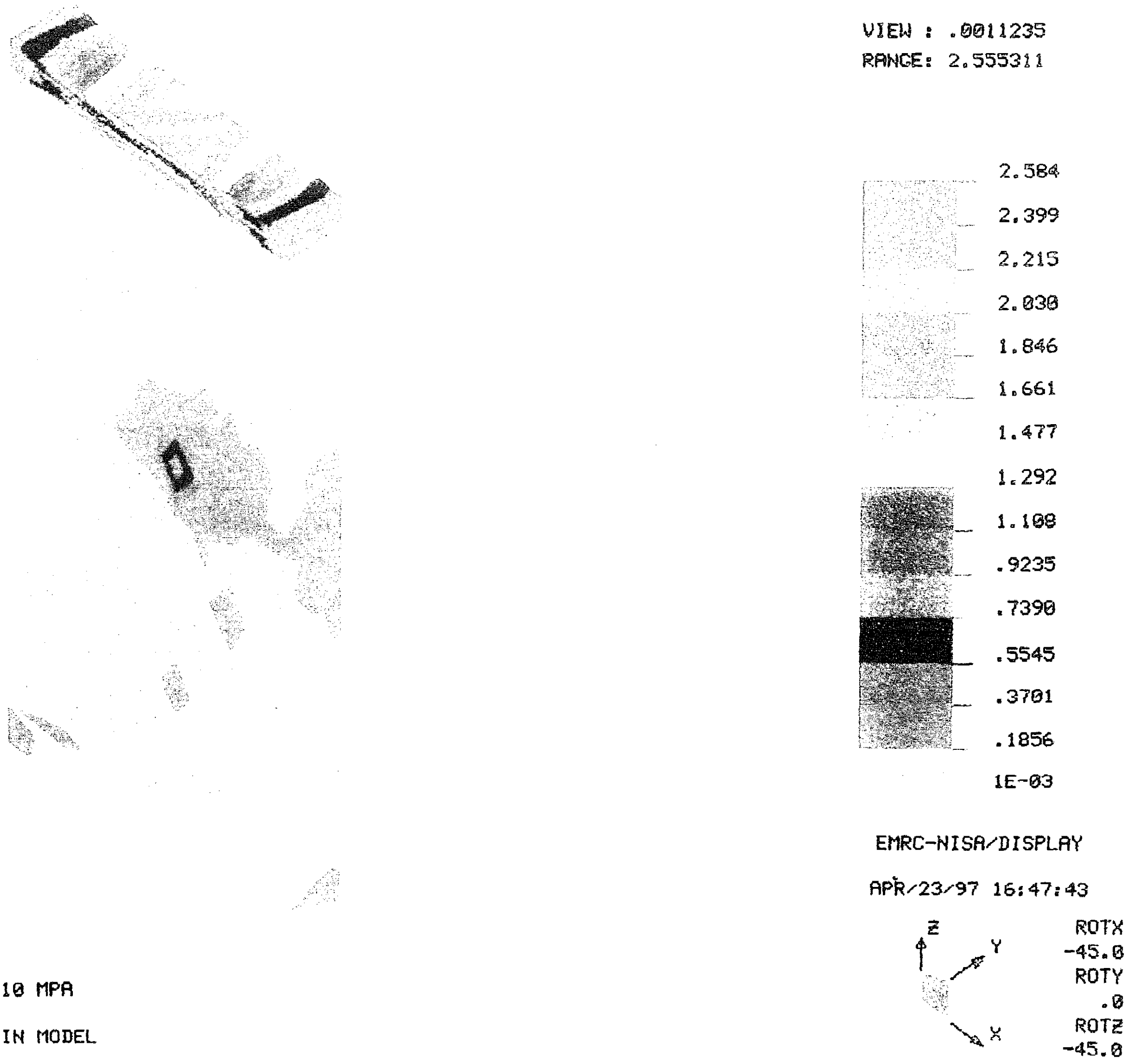
DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE



NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL

DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE



MAX. SHEAR STRS.

VIEW : .0011235
RANGE: 2.555311

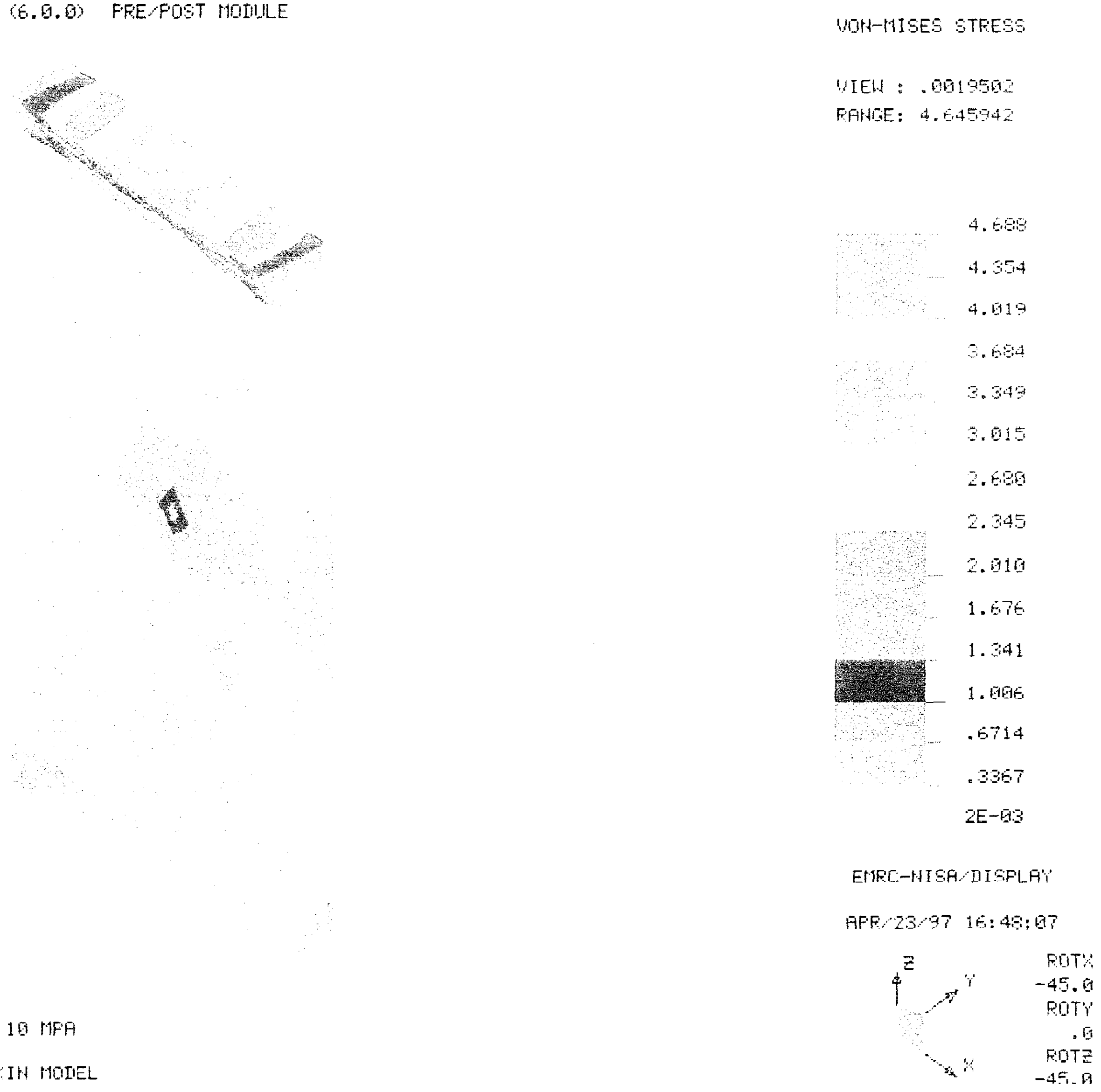
EMRC-NISA/DISPLAY

APR/23/97 16:47:43

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL

DISPLAY III - GEOMETRY MODELING SYSTEM (6.0.0) PRE/POST MODULE



EMRC

NONLINEAR STATIC ANALYSIS AT 10 MPA

FINITE ELEMENT ANALYSIS OF SKIN MODEL

REFERENCES

1. Weller, E. J., *Nontraditional Machining Process* , Society of Manufacturing Engineers, Michigan, 1984.

2. Abdou, G. H., "Analysis of Velocity Control of Water Jets for Water Jet Machining," in *Proceedings of the 1989 Los Angeles Conference on Waterjet Cutting West*, Los Angeles, California, MS89-835, 1989.

3. Benedict, G. F., *Nontraditional Manufacturing Process*, "Water Jet Machining," Marcel Dekker Inc., New York, 1987.

4. Rajurkar, K. P., "Research and Technological Developments in Nontraditional machining," *American Society of Mechanical Engineers*, PED-Vol. 34, 1988.

5. Harvey, R. L., "Major Vascular Injury from High Pressure Water Jet," *The Journal of Trauma*, Vol. 40, No. 1, 1996.

6. Chung Ho Pai, "High Pressure Injection Injuries of the Hand," *The Journal of Trauma*, Vol. 31, No. 1, 1991.

7. Neill, R. W. K., "Penetrating Intra-abdominal Injury Caused by High Pressure Water Jet," *British Medical Journal*, Vol. 2, 1969.

8. Cuschieri, A., "Experimental Evaluation of Water Jet Dissection in Endoscopic Surgery," *Endoscopic Surgery*, Vol. 2, No. 3-4, 1994.

9. Kobayashi, M., "Water Jet Angioplasty- An Experimental Study," *Acta Radiologica*, Vol. 36, No. 4, 1995.

10. Kon, Moshe, "High Pressure Water Jet Injury of the Hand," *Journal of Hand Surgery*, 10A:412-4, 1985.

11. Walker, W. A., "High-Pressure Water Injury: Case Report," *The Journal of Trauma*, Vol. 29, No.2, 1989.

12. Sander R, Poesl H., "Water Jet Guided ND:YAG Laser Coagulation -- its Application in the Field of Gastroenterology," *Endosc Surg Allied Technol*, Vol. 1, No. 4, 1993.

13. Landau D, Berson D., "High Pressure Directed Water Jets as a Cause of Severe Bilateral Intraocular Injuries," *American Journal of Ophthalmol*, Vol. 120, No. 4,1995.

14. Joseph D. Bronzino, *The Biomedical Engineering Handbook*, CRC Press Inc., Connecticut, 1995.

15. Charles D. Ray, *Medical Engineering*, Year Book Medical Publisher Inc., Chicago, 1974.

16. Richard Skalak and Shu Chien, *Handbook of Bioengineering*, Mc Graw-Hill. Inc., New York, 1987.

17. Vernon B. Mountcastle, *Medical Physiology*, C. V. Mosby Company, Saint Louis, Missouri, 1968.

18. Huebner, K. H. and Thornton, E. A., *The Finite Element Method for Engineers*, John Wiley and Sons, New York, 1982.

19. Lee, G. C. and Tseng, N.T., *Finite Elements in Biomechanics*, John Wiley and Sons, New York, 1982.

GLOSSARY

Ablation	Removal or cutting away.
Angio	Blood or lymph vessel.
Deburring	Removal of the material left after machining.
Ecchymosis	The escape of blood into the tissue from ruptured blood vessel.
Endoscopic	An instrument for visualizing the interior of hollow organ.
Gastroenterology	The study of stomach and intestines with respect to the diseases.
Hemorrhage	Bleeding.
Hyperaemia	Excess of blood in a body part from active dilation of blood vessels.
Kerfwidth	Cutting width.
Lacerations	To tear or rend roughly.
Laporatomy	Surgical section of the abdominal wall.
Leucocytosis	A white or colorless cell of the blood.
Ligation	The action of binding.
Oedema	Abnormal accumulation of serous fluid in connective tissue causing puffy swelling.
Omnidirection	Equally in all directions.
Paramedian	Situated adjacent to midline.
Peritoneal	Affecting the smooth transparent serous membrane that lines the cavity of the abdomen of a mammal.
Sphincter	To contact or close a bodily opening of channel.

Standoff distance	Distance from the nozzle of the jet to the workpiece.
Stripping	Removal of the coating on the material (workpiece).
Vitro	In glass, as in a test tube. An in vitro test is one done in the laboratory usually involving isolated tissues.
Vivo	A test performed in the living body or organism.