

Contents

Volume 2

| | |
|--|-----|
| Preface | v |
| Part 8..... | 397 |
| Method of Basic Impactors for Prediction of Penetration and Perforation..... | 397 |
| Chapter 16..... | 399 |
| Simplified Version of the Method..... | 399 |
| 16.1 Formulation of the Problem..... | 400 |
| 16.2 Solution of the Problem..... | 402 |
| 16.3 Example | 404 |
| Chapter 17..... | 407 |
| Full Version of the Method..... | 407 |
| 17.1 Formulation of the Problem..... | 409 |
| 17.2 Solution of the Problem..... | 412 |
| 17.2.1 General case | 412 |
| 17.2.2 Class of solutions | 415 |
| 17.3 Example | 418 |
| Part 9..... | 423 |
| Shape Optimization of Projectiles..... | 423 |
| Chapter 18..... | 425 |
| Survey | 425 |
| 18.1 Introduction | 425 |
| 18.2 Optimization Using Indirect Criteria..... | 426 |
| 18.3 Optimization Using Direct Criteria | 429 |
| 18.4 Some Methodological Remarks..... | 435 |
| 18.4.1 Analogy between different optimization problems | 435 |
| 18.4.2 About shape optimization of 3-D projectiles..... | 436 |
| 18.4.3 Phenomenon of cavitating penetration | 437 |
| 18.4.4 Area rules | 437 |

| | |
|--|-----|
| 18.5 Concluding Remarks | 438 |
| Chapter 19..... | 439 |
| Penetration with Non-Constant Friction..... | 439 |
| 19.1 Effect of Sliding Velocity and Pressure on Friction Coefficient. Review | 441 |
| 19.1.1 Experimental studies | 442 |
| 19.1.2 Engineering models..... | 454 |
| 19.1.3 Numerical simulations | 458 |
| 19.2 Modeling of Ballistic Characteristics | 459 |
| 19.2.1 LIMs with velocity and pressure dependent friction coefficient | 459 |
| 19.2.2 Piecewise linear approximation of generatrix | 460 |
| 19.2.3 Semi-analytical solutions | 462 |
| 19.2.4 Numerical simulations and discussion | 466 |
| 19.3 Shape Optimization of Penetrating Projectiles | 474 |
| 19.3.1 Formulation of the problem and method of solution | 474 |
| 19.3.2 Model with friction coefficient dependent on sliding velocity | 476 |
| 19.3.3 Numerical results and conclusions | 477 |
| Chapter 20..... | 485 |
| Semi-Infinite Concrete Shields | 485 |
| 20.1 Penetration Model | 486 |
| 20.2 Shape Optimization of Impactor..... | 489 |
| Chapter 21..... | 493 |
| Metal Shields Having a Finite Thickness | 493 |
| 21.1 Formulation of the Problem and Mathematical Model..... | 494 |
| 21.2 Method of Solution..... | 497 |
| 21.3 Numerical Results. Discussion and Conclusions..... | 498 |
| Chapter 22..... | 503 |
| Fiber-Reinforced Plastic Laminates | 503 |
| 22.1 Introduction | 504 |
| 22.2 Mathematical Model..... | 506 |
| 22.3 Shape Optimization of Impactors | 512 |
| 22.3.1 Classical solution on the basis of averaged model | 512 |
| 22.3.2 Interval optimal solution for truncated cones | 513 |
| 22.4 Concluding Remarks | 517 |
| Part 10..... | 519 |
| Hypervelocity Impact by Segmented Projectiles..... | 519 |
| Chapter 23..... | 521 |
| Historical Review..... | 521 |

| | |
|--|-----|
| Chapter 24..... | 555 |
| Effectiveness of Segmented Projectiles. Some Theoretical Results..... | 555 |
| 24.1 Formulation of the Problem..... | 556 |
| 24.2 Comparison of the DOP of Monolithic Projectile and Segmented Projectiles .. | 557 |
| 24.3 Optimum Segmentation..... | 558 |
| 24.4 Effect of Number of Segments on the DOP | 560 |
| 24.5 Verification of the Approach..... | 560 |
| Part 11..... | 565 |
| Segmented Impactors at High Speed Impact..... | 565 |
| Chapter 25..... | 567 |
| High Speed Impact. Simplified Discrete Model..... | 567 |
| 25.1 Formulation of the Problem..... | 568 |
| 25.2 Study of the Problem Using Two-Term Projectile-Shield Interaction Model .. | 570 |
| 25.2.1 Mathematical model..... | 570 |
| 25.2.2 Analytical study of a case of two segments..... | 571 |
| 25.2.3 Results of numerical calculations..... | 574 |
| 25.3 Study of the Problem on the Basis of Young Model | 576 |
| 25.4 General Penetration Model..... | 577 |
| 25.4.1 Formulation of problem | 577 |
| 25.4.2 Analysis of the problem | 578 |
| 25.4.3 Velocity-dependent resistance..... | 581 |
| Chapter 26..... | 583 |
| High-Speed Impact. Generalized Discrete and Continuous Models | 583 |
| 26.1 Investigation of the Problem Using a Generalized Discrete Model..... | 585 |
| 26.1.1 Formulation of the problem..... | 585 |
| 26.1.2 Analysis of the problem | 588 |
| 26.2 Investigation of the Problem Using a Continuous Model..... | 593 |
| 26.2.1 Formulation of the problem..... | 593 |
| 26.2.2 Connection between the discrete and the continuous problems | 596 |
| 26.2.3 Solution of the continuous problem | 598 |
| 26.3 Concluding Remarks | 602 |
| Part 12..... | 605 |
| Modeling and Optimal Control of Impactors with Jet Thruster | 605 |
| Chapter 27..... | 609 |
| Application of Two-Term Model of Penetration..... | 609 |
| 27.1 Formulation of the Problem..... | 611 |
| 27.2 Analytical Analysis of the Problem..... | 614 |
| 27.2.1 General properties of the extremal | 614 |

| | |
|--|-----|
| 27.2.2 Formulation of the problem for two-term model..... | 615 |
| 27.2.3 Optimum sub-arcs | 616 |
| 27.2.4 Analytical solution for a particular case | 619 |
| 27.2.5 Some simple burning programs..... | 621 |
| 27.2.6 Results of numerical calculations..... | 625 |
| 27.3 Numerical Analysis of the Problem..... | 628 |
| 27.3.1 Application of dynamic programming | 628 |
| 27.3.2 Results of numerical optimization..... | 632 |
| 27.4 Concluding Remark..... | 634 |
| Chapter 28..... | 637 |
| Application of the Modified Young Model..... | 637 |
| 28.1 Formulation of the Problem..... | 639 |
| 28.1.1 Equation for the resistance force | 639 |
| 28.1.2 Mathematical model and formulation of the problem | 641 |
| 28.2 Analytical Investigation of Limiting Case..... | 643 |
| 28.2.1 Penetration into non-frozen soil, rock, or concrete shield | 644 |
| 28.2.2 Penetration into frozen soil shield | 652 |
| 28.3 Numerical Investigation of the Problem Using Dynamic Programming | 654 |
| 28.3.1 Formulation of problem in dimensionless variables..... | 654 |
| 28.3.2 Case of general model for the resistance force | 655 |
| 28.3.3 Case of the modified Young model..... | 656 |
| 28.4 Results of Numerical Optimization | 658 |
| Part 13..... | 661 |
| Effect of Order of Plates, Layering and Spacing on Protective Properties of Shields | 661 |
| Chapter 29..... | 663 |
| Survey | 663 |
| 29.1 Introduction | 664 |
| 29.2 Shields Made of the Same Material. Effect of Layering and Spacing | 666 |
| 29.2.1 Experimental investigations | 666 |
| 29.2.2 Numerical investigations..... | 678 |
| 29.2.3 Both experimental and numerical investigations | 692 |
| 29.2.4 Publications that include theoretical analysis | 696 |
| 29.3 Shields Made of Different Materials. | 703 |
| 29.3.1 Effect of order of plates and spacing | 703 |
| 29.3.2 Choice of effective layered shield | 706 |
| 29.4 Concluding Remarks | 713 |
| Chapter 30..... | 717 |
| Effect of Spacing for Non-Conical Projectiles. Numerical Simulations | 717 |
| 30.1 Formulation of the Problem..... | 719 |

| | |
|--|-----|
| 30.2 Result of Numerical Calculations and Discussion..... | 725 |
| 30.3 Experimental Validation..... | 730 |
| Chapter 31..... | 737 |
| Effect of Order of Plates for Non-Conical Projectiles. Numerical Simulations | 737 |
| 31.1 Mathematical Model and Formulation of the Problem..... | 739 |
| 31.2 Ogive-Shape Generatrix | 742 |
| 31.3 Piecewise-Linear Approximation of Generatrix | 743 |
| 31.4 Result of Numerical Calculations and Discussion..... | 747 |
| Chapter 32..... | 753 |
| Effect of Layering. Theoretical Analysis | 753 |
| 32.1 Ballistic Properties of Layered Shields against Sharp Impactors | 754 |
| 32.1.1 Mathematical model..... | 754 |
| 32.1.2 Problem of comparison between monolithic and layered shields..... | 756 |
| 32.1.3 Worst layering for given number of layers..... | 757 |
| 32.1.4 Effect of number of layers..... | 757 |
| 32.1.5 Validation of assumptions | 758 |
| 32.1.6 Comparison with experiments. Numerical simulations and discussion.. | 760 |
| 32.2 Analysis Based on the Model by Rosenberg and Dekel | 764 |
| 32.2.1 Mathematical model and statement of the problem..... | 764 |
| 32.2.2 Investigation of the problem | 765 |
| 32.3 Analysis Based on the Model by Ilyushin | 766 |
| 32.4 Ballistic Properties of Layered Shields against Blunt Projectiles | 768 |
| 32.4.1 Mathematical model..... | 768 |
| 32.4.2 About effectiveness of layering..... | 770 |
| 32.4.3 Optimal order of plates in layered shield..... | 772 |
| 32.4.4 The case of layers having the same thickness | 775 |
| 32.5 Concluding Remarks | 776 |
| Chapter 33..... | 779 |
| Optimization of Multi-Layer Shields | 779 |
| 33.1 Formulation of the Problem and Mathematical Model..... | 780 |
| 33.2 Analysis of the Problem | 783 |
| 33.2.1 General case | 783 |
| 33.2.2 Two-layer shield | 785 |
| 33.2.3 Three-layer shield..... | 785 |
| Part 14..... | 813 |
| Some Optimization Problems for Inhomogeneous Non-Ductile Shields | 813 |
| Chapter 34..... | 815 |
| Optimization of Reinforced Concrete Panels with Steel Liner..... | 815 |

| | |
|--|-----|
| 34.1 Ballistic Properties of Multi-Layer Concrete Shields | 816 |
| 34.2 Optimization of Reinforced Concrete Panels with Rear Face Steel Liner | 819 |
| 34.2.1 Introduction | 819 |
| 34.2.2 Mathematical model and formulation of problem | 820 |
| 34.2.3 Investigation of the problem | 822 |
| Chapter 35..... | 827 |
| Optimization of Two-Component Armor against Single and Repeated Impacts..... | 827 |
| 35.1 Introduction | 829 |
| 35.2 Mathematical Model..... | 833 |
| 35.3 Reduction of Experimental Data for Alumina/Aluminum Armor | 835 |
| 35.4 Optimal Armor against Single Impact..... | 840 |
| 35.4.1 Formulation of the problem and results of calculations..... | 840 |
| 35.4.2 Characteristic property of optimal solutions..... | 842 |
| 35.5 Optimization of Armor Taking into Account Repeated Impacts | 843 |
| 35.6 Concluding Remark..... | 847 |
| Chapter 36..... | 849 |
| Optimization of Two-Component Armor Having Several Ceramic Layers | 849 |
| 36.1 Mathematical Model..... | 849 |
| 36.2 Optimization Problem | 850 |
| 36.3 Concluding Remarks | 852 |
| Part 15..... | 855 |
| Some Optimization Problems for Hypervelocity Impact | 855 |
| Chapter 37..... | 857 |
| Optimal Velocity Penetrators..... | 857 |
| 37.1 Formulation of the Problem..... | 858 |
| 37.2 Solution of Frank and Zook..... | 858 |
| 37.3 Solution of Lanz and Odermatt | 861 |
| 37.4 De Rosset and D'Amico Investigations | 863 |
| 37.4.1 The first model | 863 |
| 37.4.2 The second model | 864 |
| 37.5 Investigations on the Basis of Tate Model..... | 865 |
| 37.6 Some Related Investigations | 867 |
| Chapter 38..... | 869 |
| Optimization of Dual- and Multi-Wall Shields | 869 |
| 38.1 Dual-Wall Shields | 870 |
| 38.1.1 Shields having a minimum thickness | 870 |
| 38.1.2 Shields having a minimum areal density | 870 |
| 38.2 Multi-Wall Shields | 872 |

| | |
|---|------|
| 38.2.1 Optimization using the generalized Wilkinson model..... | 873 |
| 38.2.2 Optimization using the generalized PEN4 model..... | 874 |
| 38.2.3 Optimization using SPH and FEM methods..... | 875 |
| Appendix A..... | 879 |
| Some Properties of Convex/Concave Increasing Positive Functions | 879 |
| Appendix B..... | 893 |
| Some Experimental Studies on Penetration into Concrete or Reinforced Concrete | 893 |
| Appendix C..... | 899 |
| Some Experimental Studies on Penetration into Metals..... | 899 |
| Appendix D..... | 927 |
| Some Experimental Studies on Penetration into Geological Media..... | 927 |
| Bibliography | 931 |
| Author Index | 1047 |