FINITE ELEMENT INVESTIGATION OF LOWER EXTREMITY RESPONSE IN BLAST LOADING AND A PROPOSED DESIGN OF A LEG SURROGATE

AMAN VIKRAM

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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by

AMAN VIKRAM

Department of Mechanical Engineering

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AUTHORS DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of my thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis will be made electronically available to the public.

AMAN VIKRAM

CERTIFICATE

This is to certify that the thesis entitled "**Finite Element Investigation of Lower Extremity Response in Blast Loading; And a Proposed Design of a Leg Surrogate**" being submitted by **Mr. Aman Vikram** to the Indian Institute of Technology, Delhi, for the award of Doctor of Philosophy in the Department of Mechanical Engineering is a record of bonafide research work carried out by him. He has worked under our guidance and has fulfilled the requirements for the submission of the thesis, which, in our opinion, has reached the requisite standard.

The results in this thesis have not been submitted in part or full, to any University or Institute for the award of degree or diploma.

Dr. Anoop Chawla
Professor
Department of Mechanical Engineering
Indian Institute of Technology, Delhi

Dr. Sudipto Mukherjee
Professor
Department of Mechanical Engineering
Indian Institute of Technology, Delhi

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Aman Vikram

Indian Institute of Technology, Delhi

ABSTRACT

This thesis focuses on the numerical evaluation of lower extremity response and its injury mechanism in blast loading. It presents a numerical framework to design and validate a leg surrogate based on data generated using the THUMS^{TM} lower extremity (LE) model.

To achieve this goal, this work addresses the research question, ***"Can biofidelity and the injury predicting capability of the THUMS LE model be extended to blast loading? Can it be used to generate lower extremity response data in blast loading needed to support the design and validation of a surrogate leg?"***

Biofidelity of the THUMS LE model was evaluated against experiments with impact loading equivalent to underbody blast (UBB). CORA ratings were obtained to quantify the match. A numerical framework was developed by modelling 3D finite element simulation of landmine explosion using MM-ALE formulation. This framework was used to evaluate sensitivity of the THUMS LE model under a graded blast input in terms of explosive amount, standoff distance, and changing detonation location below the foot. The model was further investigated for its injury prediction capability by comparing the damage it predicted with experimental injuries from antipersonnel landmine blast reported in literatures. A methodology is presented to quantify the lower extremity damage in below heel antipersonnel landmine explosion. The foot was divided into three sections: the forefoot, which contains the metatarsals and phalanges; the midfoot, which includes the cuboid, navicular, and cuneiform bones; and the hindfoot, which comprises the calcaneus and talus. Tibia damage was also evaluated as it completes the load transfer path further up the leg. Further, trends for leg response and injury were developed from the simulations under varying mass of explosive and standoff detonated below heel. A numerical framework is presented to design and validate a leg surrogate for blast using the generated response data. Overall, this thesis provides insights

into lower extremity response to blast loading and lays the groundwork for further research in the field.

सार

यह थीसिस ब्लास्ट लोडिंग में निम्न पैर के प्रतिक्रिया और इसके चोट के माध्यम की संख्यात्मक मूल्यांकन पर केंद्रित है, और एक संख्यात्मक ढांचा प्रस्तुत करती है जिसका उपयोग THUMS निम्न पैर मॉडल का उपयोग करते हुए एक पैर के सरोगेट का डिज़ाइन और सत्यापन करने के लिए डेटा उत्पन्न करने के लिए किया गया है। इस लक्ष्य को प्राप्त करने के लिए, यह काम यह अनुसंधान प्रश्न पर ध्यान केंद्रित करता है, "क्या THUMS LE मॉडल की जीव रूपता और चोट पूर्वानुमान क्षमता ब्लास्ट लोडिंग तक विस्तारित की जा सकती है? क्या इसका उपयोग ब्लास्ट लोडिंग में निम्न पैर के प्रतिक्रिया डेटा उत्पन्न करने के लिए किया जा सकता है जो एक सरोगेट पैर के डिज़ाइन और सत्यापन का समर्थन करता है?"

THUMS निम्न पैर मॉडल की जीव रूपता का मूल्यांकन एक्सपरिमेंट्स के साथ किया गया जिनमें अंडरबॉडी ब्लास्ट (UBB) के समतुल्य प्रभाव के साथ हुई। CORA रेटिंग प्राप्त की गई थी ताकि मिलान का माप किया जा सके। एमएम-एलई प्रारूप का उपयोग करके लैंडमाइन विस्फोट के 3D अंतर्मूल सिमुलेशन को मॉडल करने के लिए एक संख्यात्मक ढांचा प्रस्तुत किया गया है। विकसित ढांचा का उपयोग एक्सप्लोसिव मात्रा, स्टैंडऑफ दूरी और पैर के नीचे बदलते विस्फोट स्थान के संदर्भ में THUMS निम्न पैर मॉडल की संवेदनशीलता का मूल्यांकन करने के लिए किया गया। उपयोगकर्ता द्वारा अनुमानित नुकसान की तुलना करके मॉडल द्वारा प्रस्तुत नुकसान का अध्ययन किया गया है वास्तविक दुनिया के दुर्भाग्यपूर्ण घातक ने पैर की चोट। एक तकनीक प्रस्तुत की गई है निम्न पैर में चोट की मात्रा का मापन के लिए एंटीपर्सोनल लैंडमाइन विस्फोट में नीचे एक पंजे की चोट। उत्तल नवीं मेटाटार्सल्स और फालंगेस, मध्य-पैर जिसमें क्यूबॉयड, नाविक्यूलर, और क्यूनीफॉर्म्स शामिल हैं और हिंडफुट में कैलकेनीअस और टेलस शामिल हैं। तिबिया की चोट का मूल्यांकन भी किया गया था क्योंकि यह पैर के ऊपर ज्यादा लोड स्थानांतरण पथ को पूरा करता है। इसके अलावा, अंतःपैरी विस्फोट के नीचे रखे विस्फोट के विभिन्न मास के तहत अनुसंधान से लेग की प्रतिक्रिया और चोट के लिए अवलोकन विकसित किए गए हैं। एक

संख्यात्मक ढांचा प्रस्तुत किया गया है जिसका उपयोग करके उत्तल प्रतिक्रिया डेटा जनरेट किया जाता है। सारांश में, यह थीसिस ब्लास्ट लोडिंग के लिए निम्न पैर की प्रतिक्रिया में अंदरूनी परख देती है और क्षेत्र में और अधिक अनुसंधान के लिए मूलभूत आधार रखती है।

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