Future Research Planning for Segmental Concrete Pavements

Prepared for:

icpi
Foundation for
Education and Research

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Glossary of Abbreviations

AASHTO	-	American Association of State Highway and Transportation Officials
AI	-	Artificial intelligence
ASCE	-	American Society of Civil Engineers
ASTM	-	ASTM International
CHMA	-	Concrete Masonry and Hardscapes Association
DS	-	Design and Specifications Group
EPD	-	Environmental product declaration
HVS	-	Heavy vehicle simulator
ICP	-	Interlocking concrete pavement
ICPI	-	Interlocking Concrete Pavement Institute (now CHMA)
LCCA	-	Life-cycle cost analysis
LWD	-	Light-Weight Deflectometer
MC	-	Materials and Construction Group
ME	-	Maintenance and Education Group
M-E	-	Mechanistic-empirical
MPH	-	Miles per hour
NAPA	-	National Asphalt Paving Association
PCI	-	Pavement condition index
PDP	-	Permeable Design Pro
PICP	-	Permeable interlocking concrete pavement
PMED	-	Pavement mechanistic-empirical design
UCPRC	-	University of California Pavement Research Center
USGS	-	United States Geologic Survey

Background

The ICPI Foundation (ICPIF) was created by members of the Interlocking Concrete Pavement Institute (now Concrete Masonry and Hardscapes Association (CHMA)) to advance knowledge of segmental concrete pavements. Established in 2000, the Foundation's Trustees manage investments in excess of $5 million. The mission of the ICPI Foundation is to fund targeted educational and research programs and industry tools that will benefit the segmental concrete paving industry. To date the ICPIF has provided over $2.9 million USD in grants. A list of on-going and completed projects can be seen at: https://www.masonryandhardscapes.org/icpi-foundation/research/.

Participants

The ICPIF invited a group of 19 representatives from academia, the private sector, government agencies, industry and staff of CHMA to meet and discuss future research and education needs related to segmental concrete pavements. The meeting was held in Herndon, Virginia on April 16/17, 2024. A summary of the participants by practice sector is as follows:

- Academia – 6
- Private Sector – 3
- Government – 3
- Industry – 5
- Staff – 2

A list of the focus group representatives and their affiliations is provided in Appendix A.

Expectations and Goals for the Focus Group

The expectations and goals for the focus group were as follows:

- Bring together academia, private sector, government agencies, industry and CHMA staff
- Focus on:
    - Conventional and permeable interlocking concrete pavement
    - Concrete paving slabs
    - Concrete planks
    - Concrete Grids
- Identify gaps in current knowledge
- Outline activities and research to close the gaps

Challenges, Gaps and Opportunities

The meeting commenced with an overview of previous projects and research completed by the ICPIF. This consisted of 34 projects as summarized in Appendix B. This was followed by a general presentation

of past poor experiences with segmental pavement design, specifications, materials, construction, maintenance and education. A summary of the issues presented are as follows:

- Subgrade
    - Uniformity (type of subgrade and compaction)
    - Lack of adequate subgrade drainage
    - Deleterious materials
- Bases and subbases
    - Uniformity
    - Compaction
- Bedding layer
    - Lack of adequate drainage
    - Material quality and high fines content
- Pavers, slabs and planks
    - Aspect ratio
    - Laying pattern for vehicular traffic applications
    - Cut units (placement and size)
    - Joints in concrete bases
- Geotextiles
    - Improper detailing
    - Clogging
- Utilities
    - Orientation
    - Detailing of surface around utility covers
- Other details
    - Expansion joints with above and below ground structures
    - Edge restraints
    - Surface drainage details
- Maintenance
    - Loss of jointing material
    - Surface cleaning
    - Weed growth
    - Efflorescence
- Specifications
    - Lack of designer/specifier knowledge and understanding of the products
    - Conflicting specification requirements
    - Complexity of surface design
- Quality control/assurance
    - Inspector knowledge
    - Lack of end result or performance specifications

The attendees were then divided into 3 groups to document challenges, gaps and opportunities as follows:

- Group 1 – Design and Specifications
- Group 2 – Materials and Construction
- Group 3 – Maintenance and Education

Each group included representatives from each of the 5 practice sector categories. The groups of 5 to 7 participants then discussed challenges, gaps and opportunities. On the second day of the meeting, the leader of each group presented their findings to all of the attendees. Additional comments from the attendees were then further discussed and captured.

The recommended timeline for the action item to be completed is as follows:

- Short – 0 to 2 years
- Medium – 2 to 5 years
- Long - > 5 years

Summary of Group Discussions

The manufacture of Portland cement results in the release of carbon dioxide. The group had a brief discussion on the potential ability of segmental paving products to reabsorb that carbon dioxide over the life of the product. CMHA and the ICPIF are currently exploring the amount of CO_2 that could potentially be sequestered by dry cast concrete products. Several of the workshop attendees indicated that research in this area could be beneficial for the industry.

An overall summary of the individual group discussions with challenges, gaps and opportunities along with a recommended timeline (short, medium or long-term) is provided in this section. Focus group discussion details are summarized in Appendix C.

Group 1 – Design and Specifications (DS)

Group 1 was tasked with research needs related to the design and specification of segmental concrete pavements.

DS-1. Promotion and Enhancement of Mechanistic-Empirical Pavement Design

An ICPIF project is currently underway to compile the state-of-practices for the structural design of segmental concrete pavements. Building on earlier work, including the construction and heavy vehicle simulator testing of a PICP, the deliverables for the project will be a mechanistic-empirical model and web catalog for ICP. The next step for ICP would be a project to evaluate the impact of key design features including unit thickness, size and shape, laying pattern, bedding and joint sand, traffic, environment (moisture and coefficient of expansion), impact of 2-D and 3-D interlock units, etc. In addition, the use of geosynthetics and recycled materials on the performance of the pavement was noted. This information would assist in codifying much of the anecdotal information that is currently

being used to determine and judge ICP performance. Finally, the need to promote to the engineering community that these design resources exist is paramount.

DS-2. Holistic Hydrologic Design for PICP

While there has been significant work on the hydrologic design of PICP, the current models are not holistic in the treatment of water balance including surface flow, evaporation, infiltration, pipe and outflow drainage and the impact of other below pavement surface features such as slope berms. Comprehensive and seamless integration of the PICP contribution to water balance is critical for the assessment of the benefit of PICP to climate change, water recycling, water temperature reduction and overall transportation infrastructure resilience. Currently used hydrologic models are based on individual PICP installations and cannot be directly transferred into commonly used large scale watershed modelling software.

DS-3. Promote Specifications

A wide variety of construction material and placement specifications are used by transportation agencies. While CMHA has developed guide specifications, their importance and use for segmental concrete pavements is critical to ensuring compliance with design and construction and to ensure the longevity of the pavement. ICP and PICP compliance with project specifications can be verified prior to installation as opposed to asphalt and concrete which are verified until after they have been installed.

Many transportation agencies use end-result specifications and/or are moving to performance-based specifications where the ultimate performance of the pavement is predicted based on mechanistic-empirical design for compliance with the expected performance of the pavement. One of the key life-cycle cost benefits of segmental concrete pavements is a long performance life and acceptance of the final product should be reflected in the specifications.

Group 2 – Materials and Construction (MC)

MC-1. Product Category Rules and Environmental Product Declarations

While product category rules (PCR) have been developed for segmental paving units, the requirement for environmental product declarations is rapidly expanding with some agencies being restricted from specifying products that do not have EPDs. Both the asphalt and concrete pavement industries have been focusing on being EPD compliant. The expanded use of EPDs as a framework for promoting the benefits of concrete pavers and for life-cycle comparisons with other pavement materials should be explored.

MC-2. Induction Charging for ICP Pavements

With the rapid transition from carbon fuel to electric powered vehicles there has been a large boost in the development of in-pavement induction-based charging systems. Segmental concrete pavements could have a potential benefit compared to asphalt or concrete surface pavements in that segmental pavements can be potentially “unzipped” to access in-pavement infrastructure for repairs or

replacement and then "zipped" back together with little to no damage to the pavement. The purpose of this project would be to determine the efficiency and benefits of induction charging systems for ICP parking area pavements.

MC-3. Quality Control and Assurance Plans

Pavement owners place higher performance and aesthetic requirements on segmental concrete pavement compared to asphalt and concrete pavement surfaces. Owners and construction inspectors are not as familiar with ICP construction quality control and assurance requirements for segmental concrete pavement systems. The purpose of this project would be to develop holistic quality control and assurance programs for the entire segmental pavement system. This could include the development and offering of training courses for both installation and maintenance best practices. The training materials should be relevant to both contractors and inspectors, and address of new methods of construction such as the use of the Light-Weight Deflectometer to verify base and subbase compaction.

MC-4. Innovation in Sustainable Pavement Materials

Innovations in pavements and materials is an on-going process and once mastered, frequently become standardized. It is difficult for many manufacturers to keep up with and understand the benefits of alternative materials such as the use of supplemental cementitious materials, recycled products and "green" technology. This project would include a global literature survey to gather and analyze data on innovative materials, pavement design, production, construction and asset management elements that offer enhanced performance, efficiency, cost-effectiveness and alignment with environmental stewardship for the use by the segmental concrete pavement industry.

MC-5. "Hey CMHA" Artificial Intelligence for CHMA Website

To improve the design and construction of segmental concrete pavements, it is important to make it easy for users to access industry best practices. Several of the meeting attendees expressed that they did not realize how much information was already available from CMHA. While much of this information is available in the form of research reports, technical notes and specifications, its dissemination to users should be made simple and easy. The hot-mix asphalt industry had developed an artificial intelligence inspired addition to their website called "Hey NAPA" where users access NAPA's body of knowledge by asking questions. See: https://www.asphaltpavement.org/news-resources/hey-napa

Group 3 – Maintenance and Education (MS)

ME-1. Field Guides and Agreements for Maintenance

One of the common problems with segmental concrete pavements is the unfamiliarity of the products by operations and maintenance staff from owners/agencies. This project would focus on simple and practical guidance for those responsible for pavement maintenance. It would develop step-by-step field guides and best practice videos for pavement maintenance personnel and model agreements for outsourced maintenance activities.

ME-2. Document Pollution Reduction for PICP

While much work has been completed to document the pollutant reduction potential of permeable pavements there is a need to transition from the "it works" stage to the standard practice quantification and prioritization of the benefits in terms of water temperature (cooling potential), nitrogen reduction, micro-plastics, 6PPD-Quinone (organic chemical widely used as a stabilising additive in tire rubber and is toxic to aquatic species), polyfluoroalkyl substances (PFAS), etc.

ME-3. Body of Knowledge and Maintenance Training

In support of Item MC-5, the compiled body of knowledge can be used as a starting point to develop a plan to provide industry funded training for public agency operations and maintenance staff, pre-conference workshops, academic licensing of civil design materials and a focus on knowledge transfer through teaching schools to assist in elevating the knowledge of segmental concrete pavements.

Ranking of Challenges and Opportunities

In terms of the recommended focus priority, each of the non-staff participants (17 in total) was provided with sticky notes with the numbers 1 through 5. Each was asked to apply their points to what they felt was the highest priority with 5 points given to their highest priority and 1 point to their lowest priority. The number of points awarded provides and indication of what the group felt was the highest priority. The total number of points that were assigned was 255. The recommended focus priorities from highest to lowest is summarized in Table 1.

Table 1. Focus Group Priority Rankings.

Item	Proposed Action	Rank	Points	Timeline (years)
DS-1	Promotion and enhancement of mechanistic-empirical pavement design	1	42	>5
DS-3	Promote specifications	2	35	0 – 2
DS-2	Holistic hydrologic design for PICP	3	34	2 – > 5
ME-3	Body of knowledge and maintenance training	4	32	0 – 2
MC-5	Hey CMHA artificial intelligence for CMHA website	5	27	0 – 2
MC-2	Induction charging for ICP pavements	6	20	0 – 5
ME-1	Field guides and agreements for maintenance	7	19	0 – 2
ME-2	Document pollution reduction for PICP	8	19	0 – 2
MC-3	Quality control and assurance plans	9	16	0 – 2
MC-4	Innovation in sustainable pavement materials	10	7	0 – 5
MC-1	Base framework for EPDs	11	4	2 – 5

DS = Design and Specifications. MC = Materials and Construction. ME = Maintenance and Education.

Conclusions

The challenges, gaps and opportunities identified in the report should allow the ICPI Foundation to solicit proposals for important and needed research and education programs.

This report should also inform Education, Marketing and Technical programs at the Concrete Masonry and Hardscapes Association.

Future Research Focus Group sessions like this one should be held on a regular basis to track new challenges and opportunities while evaluating the progress made on the initiatives identified.

Appendix A

Research Needs Focus Group Attendees

Focus Group Attendee List

First	Last	Practice Sector	Affiliation
Jennifer	Drake	Academia	Carleton University
David	Jones	Academia	UC Davis
Somayeh	Nassiri	Academia	UC Davis
Deb	Mishra	Academia	Oklahoma State
Ryan	Winston	Academia	Ohio State
Tyler	Munk	Academia	Utah State
David	Hein	Private Sector	Independent Consultant
Gonzalo	Rada	Private Sector	WSP
Mark	Smallridge	Private Sector	Mark Smallridge and Associates
Brik	Zivkovich	Government	Mile High Flood District
Ruby	Wei	Government	NYC Parks
Elizabeth	Fassman-Beck	Government	Southern California Coastal Water Research
David	Hasness	Industry	Keystone Hardscapes
Kevin	Earley	Industry	Oldcastle APG
Paul	Cureton	Industry	Oldcastle APG
Glenn	Herold	Industry	Brampton Brick
Joe	Kerrigan	Industry	Basalite
Bryan	Horr	Staff	CMHA
Robert	Bowers	Staff	CMHA

Appendix B

ICPIF Project Summaries (2006-2024)

ICPIF Project Summaries (2006-2024)

Year	Project	Purpose/Outcome
ICP Characteristics and Benefits		
2014	Pathway Roughness Tool	• Measure roughness of pedestrian pavements • Basis for ASTM E3028 • Adopted by U.S. Access Board
2015	Howard Road Performance	• Use of ASTM E2840 pavement surface condition index for ICP
2019	Wheelchair-Pavement Interaction	• Confirmed acceptability of ICP and PICP surfaces for wheelchair users
2022	Traffic Calming Effects of ICP	• Traffic speed measurements on pavers versus asphalt surfaces • Rate of motorists traveling above 29 MPH was 4 times greater on asphalt versus paver surfaces
ICP Life-Cycle Cost Analysis		
2019	Leesburg, Virginia ICP Performance Modelling	• Included initial, maintenance and rehabilitation costs, user delays and the impact of utility cuts • Documented life-cycle cost savings
2022	ICP Municipal Pavement LCCA Cost Comparisons	• 11 municipalities in the U.S. and Canada • 32 combinations of traffic, soil types and pavement structures • Roadways and parking lots, sidewalks and trails • Included user delay and impact of utility cuts
2024	Mechanistic-Empirical Modeling	• Application of Caltrans M-E pavement design to ICP • Examines stress distributions from pavers and bedding sand into a range of bases, subgrades, climate and traffic conditions
2024	Edge Restraint Analysis	• Addresses the stability of a variety of edge restraints • Development of a standard test method
PICP Structural, Surface and Subsurface Performance		
2010	Permeable Design Pro Software	• Structural and hydrologic design for PICP • Design guidance for permeable pavements using the AASHTO pavement design method
2014	Mechanistic Modeling, Validation and Structural Design	• Full-scale accelerated load testing to validate and calibrate a PICP design model • Codified in ASCE 68-18 Permeable Interlocking Concrete Pavement Standard
2016	PICP over Clay Soils	• Monitoring of hydrologic and pollutant removal performance over low-infiltration clay soils • Mitigates against the use of limiting PICP in soils with low infiltration capacity
2016	Hydraulic Design of PICP	• PICP surface flow determination for various slopes, joint widths and aggregate types • More frequent surface cleaning needed for smaller joint sizes and aggregates

Year	Project	Purpose/Outcome
2019	Permeable Design Pro Software Update	• Updated software to include the mechanistic-empirical pavement design method (ASCE Method) developed from the 2013 validation study
2020	Permeability Restoration of PICP	• Performance testing of various cleaning equipment • Equipment performance guidelines incorporated into association technical literature
PICP Cold Climate Performance		
2013	New Hampshire Stormwater Center	• Monitored stormwater volume and pollutant load reductions • Pollutant reductions extended a month longer into winter freeze and a month earlier in spring thaw than impervious bases • Demonstrated viability of PICP in cold climates
2016	Long-Term PICP Performance	• 5 year performance study to demonstrate pollutant reduction • Demonstrated viability of PICP in cold climates
2018	U.S. Geologic Survey Study (Wisconsin)	• Established pollution reduction credits • Vacuum cleaning trials demonstrated high restoration of surface infiltration designs
2020	Winter De-icing Operations for PICP	• Measured PICP friction levels compared to asphalt surfaces • Demonstrated reduction in deicing needs • Meltwater infiltrated into the PICP leaving the surface dry
Open-Graded Aggregate Base/Subbase Studies		
2022	Compaction Verification with Light-Weight Deflectometer	• Laboratory and field trials of compacted open graded bases for PICP • Established deflection testing frequencies and acceptance criteria
2023	Performance of Open-Graded Bases	• Laboratory and field trials to establish performance
2024	Open-Graded Base Compaction	• Assesses relationship between compactor/compaction force/amplitude/ frequency, aggregate gradation and lift thickness • Development of a prescriptive compaction control protocol for open-graded aggregate layers
Strategic PICP Projects		
2018	Permeable Pavement Road Map	• Workshop of 50 participants from industry, government and academia • Bridge cap between stormwater and road agencies • Develop planning guidance • Accurate LCCA • Design decision trees • Reduce urban flooding • Reliable pavement structural designs • High quality construction • Maintenance best practices

Year	Project	Purpose/Outcome
		• Incorporation of PICP into agency asset management systems • Establish best practice clearing house for permeable pavements
2018	On- and Off-Site Benefits from Permeable Pavements	• Life-Cycle tools to assess benefits of multiple components of permeable pavement • Validates the use of PICP
Segmental Concrete Paving Slabs		
2014	Design Tables for Paving Slabs	• Finite element modeling of structural capacity for a range of sand-set paving slabs and planks over aggregate, lean concrete and concrete base
2022	Full-Scale Load Testing for Paving Slabs	• Field trials for validation of FE Modeling • Resulted in a Technical Note for paving slab design
2023	Development of an ASTM Test Method for Pedestal-Set Slabs	• Investigated support and loading conditions • Developed test method for approval by ASTM C15 committee
Sustainability and Mitigation of Global Warming		
2014	Product Category Rules for Segmental Pavement	• Guidance for Environmental Product Declarations
2024	CO_2 Sequestration Study	• Examines and quantifies carbonation by concrete pavers
Education Projects		
2006	8th International Conference on Concrete Block Paving	• Support of conference (400 attendees)
2010	Paveshare Website for Landscape Architect Students	• Includes lecture presentations, quizzes, studio projects case studies, animations and links to ICPI resources
2015	Education Tools for Landscape Performance	• Sponsored 10 grands to university landscape architecture facilities • Resources for educators
2021	Tools for Schools Grant Program	• Annual program to community colleges and universities • Supports schools that align with industry recommendations for installer training and competencies
2021-2023	Job Task Analysis for ICP/PICP Construction	• Identifies best practices for ICP construction • Positions segmental paving installation to be become an apprenticed construction trade
2024	Workforce Development through SkillsUSA	• Funds participation in the national competition • Supports hardscaping materials and construction as a viable career for students

Appendix C

Detailed Summary of Focus Group Discussions

Pavement Design and Specifications

Item	Challenge	Gap	Approach to Fill Gap	Proposed Action	Timeline (Years)	Who Should Do It
DS-1	Improved precision and flexibility for pavement system design	Design inputs for full pavement mechanistic-empirical design	1. Evaluate the impact of key design factors a. Unit thickness b. Unit size and shape c. Laying pattern d. Bedding sand e. Joint sand f. Traffic g. Environment (moisture, coefficient of thermal expansion) h. Geosynthetics i. Recycled products 2. Collate available research to assess the potential impact of key design factors for potential further study	1. Assess and prioritize the impact of key design factors 2. Continue work initiated with the UCPRC 3. Incorporate recommendations from Permeable Pavement Roadmap Routes 5 and 6 4. Build a PMED solution for all segmental pavement types	>5	Academic or consultant
DS-2	Water flow and balance for permeable pavement	Improve hydrologic design for permeable pavements Link water flow with common hydrologic models on the network level	1. Quantify full pavement water balance including: a. Evaporation b. Surface flow (slopes) c. Infiltration d. Pipe and outflow drainage e. Model the impact of in-pavement berms 2. Design for stormwater capture/reuse 3. Real time (active) water control 4. Life-cycle model of clogging on performance 5. Benefits for climate change a. Improved resilience with stormwater capture b. Reduce thermal transfer c. Evaporation pavements	1. Build on 2014-2024 research projects to develop a holistic hydrologic design solution for permeable pavements	2 – >5	Academic or consultant
DS-2	Too many variations of construction specifications used by public sector agencies and associations	Need to develop end result or performance-based specifications to ensure good design and construction	1. Make it easy for designers and agencies to use CMHA product and placement specifications 2. Institute regular reviews of product and placement specifications	1. Actively promote CHMA product and placement specifications 2. Develop a body of specification knowledge (cause and effect) and publish on the CHMA website	0 – 2	Consultant or CHMA

Materials and Construction

Item	Challenge	Gap	Approach to Fill Gap	Proposed Action	Timeline (years)	Who Should Do It
MC-1	Environmental product declarations (EPDs) are becoming a required submission for contracting purposes	The majority of CMHA members so not have environmental product declarations (EPDs)	1. Due to the variety of product materials, it would be difficult to prepare one EPD for all manufacturers	1. Develop a base framework for a typical EPD for use by members	2 – >5	Consultant or CMHA
MC-2	Improving access to electric vehicle charging systems	Determining the feasibility of using segmental pavement for inductive charging for electric vehicles	1. Determine the feasibility of installing induction charging systems within parking stall segmental pavement systems	1. Complete laboratory trials to determine the efficiency and benefits of induction charging systems for ICP pavements	0 – 5	Academic or consultant
MC-3	Poor performance of segmental pavements due to improper construction	Owners and inspectors are not familiar with construction quality control and assurance requirements for segmental pavements	1. Provide technical guidance and training for owners and construction inspectors	1. Develop quality control and assurance programs for the entire segmental pavement system 2. Develop and offer training courses 3. Develop a light-weight deflectometer promotion program for PICP base/ subbase compaction	0 – 2	Consultant or CHMA
MC-4	Innovation in sustainable pavement materials	Understanding the impact and benefits of alternative materials	1. Conduct a series of laboratory research programs 2. Expand the promotion and use of EPDs to quantify the benefits of alterative pavement materials	1. Use of supplemental cementitious materials 2. Use of recycled concrete materials for segmental paving systems 3. Assess methods to increase the albedo of the surface	0 – 5	Academia, Consultant or CHMA
MC-5	Improve design and construction quality for segmental pavement systems	Dissemination of best practices for design and construction	1. Make it easy for users to access industry best practices for design and construction guidance	1. Develop a consolidated body of knowledge for design and construction 2. Disseminate knowledge using a “Hey NAPA” type of artificial intelligence application for the CMHA website	0 – 2	Consultant and CHMA

Maintenance and Education

Item	Challenge	Gap	Approach to Fill Gap	Proposed Action	Timeline (years)	Who Should Do It
ME-1	Active maintenance of segmental pavements	Lack of experience with segmental pavements	1. Provide simple and practical guidance for those responsible for pavement maintenance	1. Develop model agreements for maintenance of segmental pavement systems 2. Develop step by step field guides for pavement maintenance personnel 3. Emphasize the responsibility for appropriate maintenance	0 – 2	Academic or consultant
ME-2	Assessing the contribution of pollution reduction for permeable pavements	Definitive impact of pollution reduction abilities of permeable pavements	1. Laboratory and field trials to document PICP pollution reduction for elements such as water temperature (cooling potential), micro-plastics and tire wear, etc.	1. Review of completed research to prioritize the maximum potential benefits of PICP for pollution reduction 2. Experiments to document PICP pollution reduction capability	0 – 2	Academic or consultant
ME-3	Education and training for the maintenance of segmental pavement systems	Dissemination of best practices for segmental pavement maintenance	1. Make it easier to access CHMA recommended best practices (see Hey NAPA AI in Materials and Construction)	1. Compile a body of knowledge for segmental pavement maintenance practices (more persuasive than one-off reports) 2. Industry funded training for public operation and maintenance staff 3. Offer pre-conference workshops at appropriate events 4. Academic licensing of civil design materials 5. Focus on teaching schools not research schools	0 – 2	Academic, consultant or CHMA